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Domestic and Global Wind Power Markets for Large and Small Wind Turbines:

A Collection of Information for Wind Sail, LLC

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Disclaimer

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1. Introduction

Wind Sail, LLC ("Wind Sail") is a start-up wind power company consisting of U.S. and Russian entrepreneurs that hold the rights outside of Russia to a series of low-maintenance vertical axis wind turbines being designed and built in collaboration with Empire Magnetics (Rohnert Park, California) and the State Rocket Center (SRC) Makeyev Design Bureau (Chelyabinsk, Russia). The United States Department of Energy's Initiative for Proliferation Prevention has awarded a grant to Wind Sail to assist in the commercial development of such turbines; this grant is being managed by Lawrence Berkeley National Laboratory's (LBNL) Engineering Division. As part of the development process, Wind Sail is gathering information on potential markets for its product. To that end, this report (authored by analysts within LBNL's Environmental Energy Technologies Division) is intended to provide Wind Sail with objective information on large (utility-scale) and small (customer-sited) wind power turbines and markets primarily in the United States, but also globally where relevant information is readily available. Our purpose is not to arrive at specific recommendations as to which markets Wind Sail should pursue, but rather to provide a reference document that can help Wind Sail to make such decisions.

This report proceeds as follows. Chapter 2 provides a brief overview of the size of the global wind power market, focusing almost exclusively on *utility-scale* turbines,[1] as small customer-sited wind turbines get lost in the noise at such a low level of resolution. Chapter 3 then delves into a much greater level of detail with respect to the utility-scale wind power market in the United States; this is the authors' primary area of expertise, and is also where data availability is the highest. In Chapter 4, we assess – to the best of our ability, given data constraints – the small wind turbine market both domestically and globally.

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[1] Though the cutoff point is somewhat arbitrary and will depend on the particular turbine's vintage (e.g., some of the early utility-scale turbines installed in California are now quite small by today's standards), utility-scale turbines can generally be defined as those that are greater than 100 kW of nameplate capacity. In today's market, however, where many turbine manufacturers no longer offer turbines <600 kW, any new utility-scale turbine will be substantially larger than 100 kW.

2. Assessing the Size of the Global Wind Power Market

According to BTM Consult ApS (2002), 6,824 MW of new wind capacity was installed globally in 2001, bringing total cumulative capacity to 24,900 MW. *Windpower Monthly* had slightly different numbers, with 6,765 MW of new capacity in 2001 bringing total global capacity to 24,481 MW. Note that these numbers represent grid-connected, utility-scale turbines only.

Figure 1 depicts the strong growth in the wind industry over the past decade. The shaded area indicates annual capacity additions (left scale), while the line represents cumulative capacity (right scale).

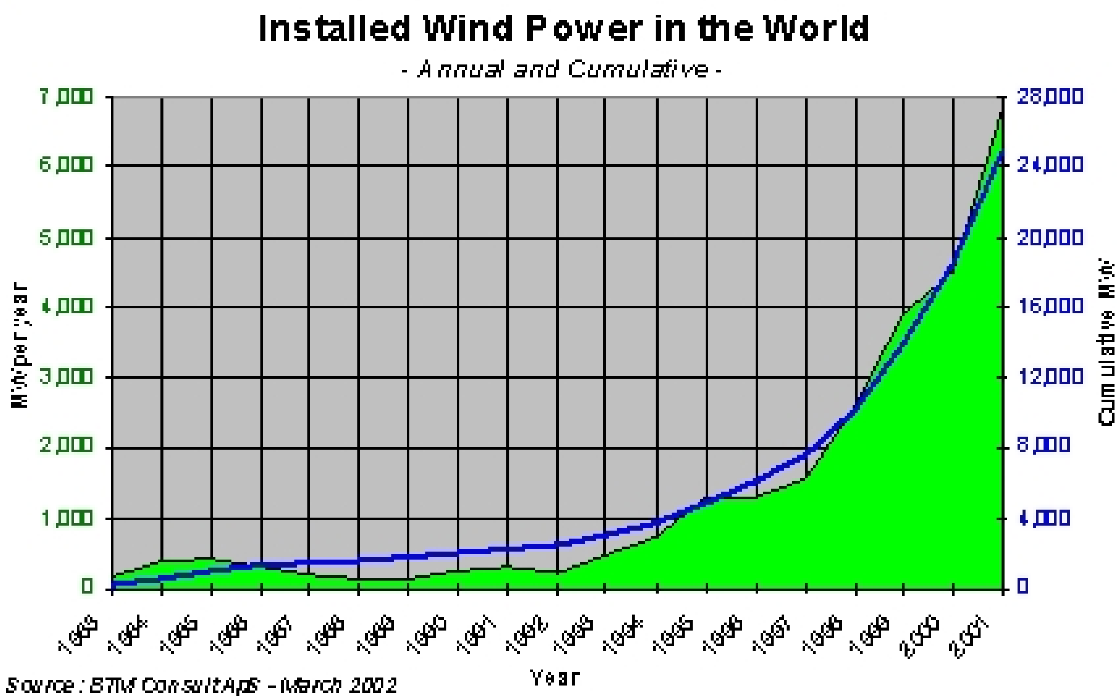


Figure 1: Global Annual and Cumulative Installed Wind Capacity

The July 2002 issue of *Windpower Monthly* provides a mid-year estimate of installed global wind capacity (25,824 MW), as well as a country breakdown. Table 1 shows this breakout (first column), as well as the amount of capacity added in each country in the past year-and-a-half (8,118 MW in aggregate).

Table 1: Global Installed Wind Capacity Through June 2002 (MW)

	Cumulative Installed Capacity Through June 2002 (MW)	Installed Capacity Since 12/31/2000 (MW)
Germany	9,500	3,387
USA	4,251	1,696
Spain	3,712	1,310
Denmark	2,456	159
India	1,627	407
Italy	700	311
Netherlands	501	53
UK	498	89
China	399	59
Japan	300	150
Sweden	280	49
Greece	272	83
Canada	207	67
Portugal	127	27
Ireland	125	7
Egypt	125	62
Austria	95	17
France	85	6
Australia	73	39
Costa Rica	71	20
Morocco	54	0
Finland	41	3
Ukraine	40	35
New Zealand	37	0
Belgium	31	22
Poland	28	21
Argentina	24	10
Czech Republic	23	16
Brazil	20	0
Turkey	19	0
Norway	17	4
Luxembourg	15	5
Caribbean	13	0
Iran	11	0
South Korea	8	0
Israel	8	0
Russia	5	0
Switzerland	5	2
Mexico	5	0
Sri Lanka	3	0
Taiwan	3	0
Africa	3	0
Chile	2	2
Jordan	2	0
Hungary	1	1
Latvia	1	0
Romania	1	0
Total	**25,824**	**8,118**

Source: WINDPOWER MONTHLY, July 2002

Figure 2 shows BTM's (2002) estimate of actual annual global wind power development through 2001, plus a forecast of annual global development through 2006. At this predicted pace of growth, global cumulative wind capacity will reach nearly 80,000 MW by 2006 – a tripling of installed capacity in just 5 years. Note that the lion's share of forecast development is in Europe, where the EC has set a goal of 40,000 MW of wind power by 2010 in Europe alone (EWEA is targeting 60,000 MW of wind in Europe by 2010). The spike in the U.S. in 2003 is related to the scheduled expiration of the federal production tax credit for wind in December 2003.

While the optimism inherent in this forecast could easily lead one to view it with skepticism, we note that among the many different forecasts of installed wind capacity that are available, BTM's forecasts are considered to be fairly reliable. BTM's annual *World Market Update* is one of the most often cited documents in the realm of forecasting.

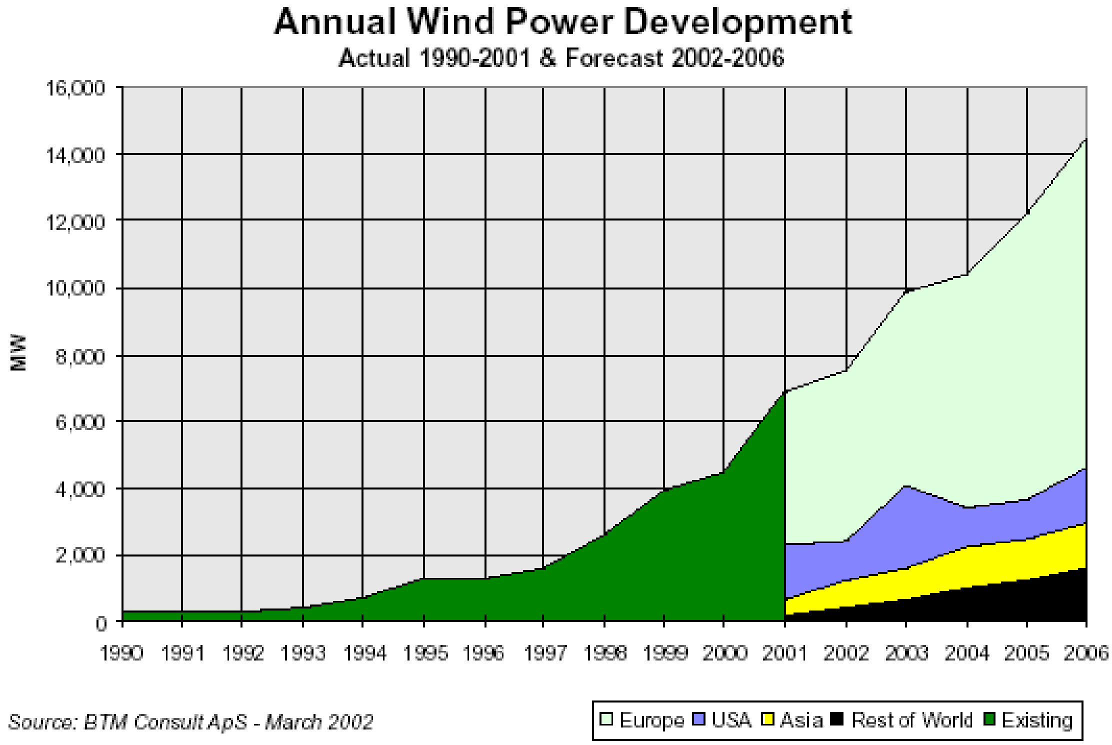


Figure 2: Annual Global Wind Power Development, Actual and Forecast (MW)

BTM (2001) also presents this 5-year forecast at the country level. Countries that are expected to be major contributors from 2002-2005 include Spain (6,800 MW from 2002-2005), Germany (6,500 MW), the U.S. (3,400 MW), France (1,900 MW), India (1,450 MW), the UK (1,350 MW), Denmark (1,250 MW), Italy (1,200 MW), and China (1,100 MW). Potentially of interest to Wind Sail, BTM's forecast for the former Soviet Union is 380 MW from 2002-2005.

Over the longer term, BTM (2002) predicts that by 2010, cumulative global wind capacity will reach 144,000 MW, which translates into a growth rate of 26%/year until 2005 and then 20%/year from 2005-2010. Note that this *prediction* is considerably more uncertain than BTM's 5-year *forecast* due to the extended time horizon, as well as uncertainty over what types of policy and economic drivers will exist over more than the next few years.

For example, as part of market liberalization, the European Union hopes to see its member countries' incentive policies for renewable energy converge within a few years, but at this time it is not clear which of the competing policies in Europe will win out – aggressive feed-in tariffs which have driven the bulk of European wind installations to date (e.g., in Germany), or renewables portfolio standards (RPS) that are currently being launched in the UK, Italy, Sweden, Belgium, and a few other countries. To underscore this point, the Dutch consulting firm ECOFYS estimates that with a continuation of *current* policy through 2010, installed wind capacity in Europe will reach 54,000 MW (ECOFYS 2002). If, however, all approved policies (as of 9/1/2001) are enacted as scheduled, installed wind capacity in Europe will grow to only 37,000 MW by 2010. This difference reflects a shift away from lucrative feed-in tariffs towards more market-based policies that will likely not be as favorable to wind developers.

The pace of offshore development will be a key factor in determining whether forecasts of installed capacity are met, particularly in Europe. Many large (i.e., hundreds of MW) offshore projects are currently in the planning stages for Europe (and a few in the US), but few are actually under construction at this point, and it remains to be seen whether legal and permitting hurdles can be overcome in time for the offshore market to be a major contributor to capacity targets for 2010.

Finally, by 2010 wind power may become economical without incentives in many cases, yet this driver is difficult to predict. Another wildcard is climate policy – Kyoto Protocol targets are currently driving some of the stated wind development goals in Europe, and the establishment of more binding policies such as a carbon tax could also be a major driver for wind power.

Globally, the average size of all wind turbines installed in 2001 was 915 kW (BTM 2002) – a 14% increase from 800 kW in 2000. Data on average size of annual wind turbine installations in select countries is provided in Table 2 (BTM 2001).

Table 2: Average Size of Wind Turbine Generators Installed Each Year

	China	Denmark	Germany	India	Spain	Sweden	UK	US
1995	326	493	473	208	297	448	534	327
1996	400	531	530	301	420	459	562	511
1997	472	560	623	279	422	550	514	707
1998	636	687	783	283	504	590	615	723
1999	610	750	919	283	589	775	617	720
2000	600	931	1,101	401	648	802	795	686

Source: BTM Consult, "International Wind Energy Development: World Market Update 2000", March 2001

On a cumulative basis, the average size of all wind turbines globally in 2000 was 375 kW. Data on average turbine size of cumulative installations for select countries is provided in Table 3.

Table 3: Average Size of Wind Turbine Generators of Cumulative Installations

	China	Denmark	Germany	India	Spain	Sweden	UK	US
1995	147	148	310	199	177	311	360	118
1996	209	181	358	222	258	345	398	120
1997	281	235	402	228	323	364	425	125
1998	362	271	465	233	367	412	442	132
1999	441	303	562	232	455	453	450	153
2000	479	366	646	258	510	489	484	161

Source: BTM Consult, "International Wind Energy Development: World Market Update 2000", March 2001

Table 4 segments installed capacity in 2000 into three product size categories. While medium-sized turbines held 59% market share in 2000, MW-class turbines were closing in at 39% market share, a trend that likely continued in 2001 and 2002.

Table 4: Segmentation of Installed Turbines by Size in 2000

	Number of Turbines	Installed Capacity	Market Share (by capacity)	Avg Turbine Size	Current Trend
<500 kW	311	84 MW	1.8%	270 kW	Fast decreasing
500-999 kW	4,087	2,685 MW	59.0%	657 kW	Slightly decreasing
>1 MW	1,293	1,779 MW	39.1%	1,376 kW	Increasing
Total	**5,691**	**4,548 MW**	**100%**	**800 kW**	

Source: BTM Consult, "International Wind Energy Development: World Market Update 2000", March 2001

In summary, the global wind power sector as a whole has been growing at a phenomenal pace, and strong growth is predicted to continue well into the future. Turbine size has been growing rapidly, to the point where megawatt-class machines are now considered the norm, and the industry is developing 3+ MW machines for offshore use.

3. Utility-Scale Wind Projects in the U.S.

This chapter pertains to utility-scale wind turbines used to supply power to wholesale electricity markets through power sales agreements with utilities or other electricity suppliers. This is the principal market for wind turbines in the United States and internationally. Again, for the purposes of this report, we define *utility-scale* turbines to be any that are larger than 100 kW in nameplate capacity (and conversely, we define small wind turbines to be those sized up to 100 kW).

3.1 Market Size and Potential

3.1.1 <u>Current Market Size</u>

Figure 3 shows the current size of the utility-scale wind power market in the U.S., as well as historic growth over time. According to AWEA, there were 4,685 MW of installed utility-scale wind capacity in the U.S. at the end of 2002 (for comparison purposes, AWEA estimates that there are roughly 15 MW of installed *small wind* capacity in the U.S.) The spikes in installed capacity in 1999 and 2001 reflect the expiration of the federal production tax credit (1.8¢/kWh in 2002) in each of those years (more on the PTC below).

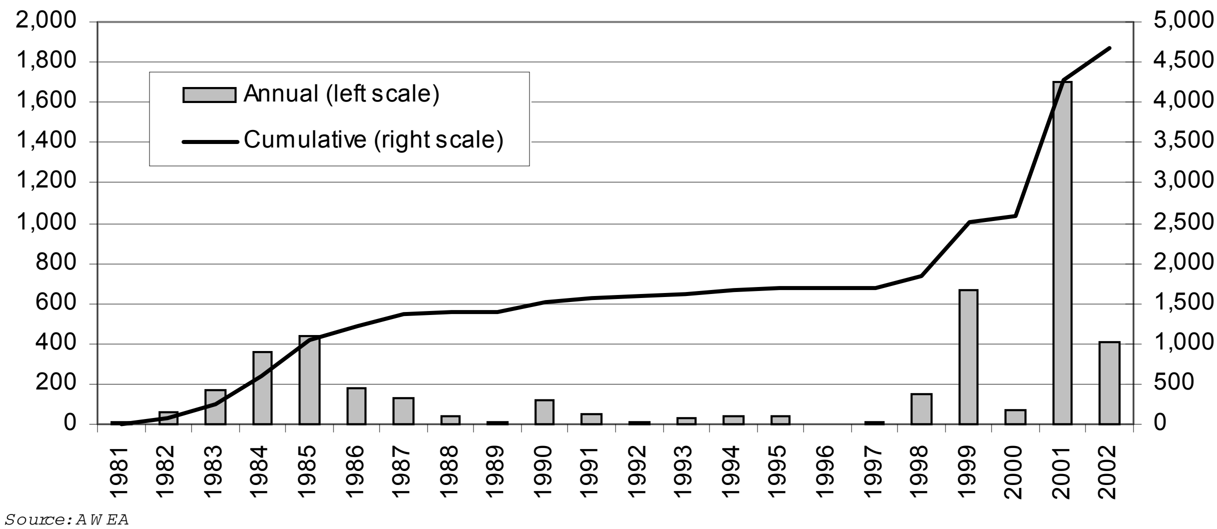
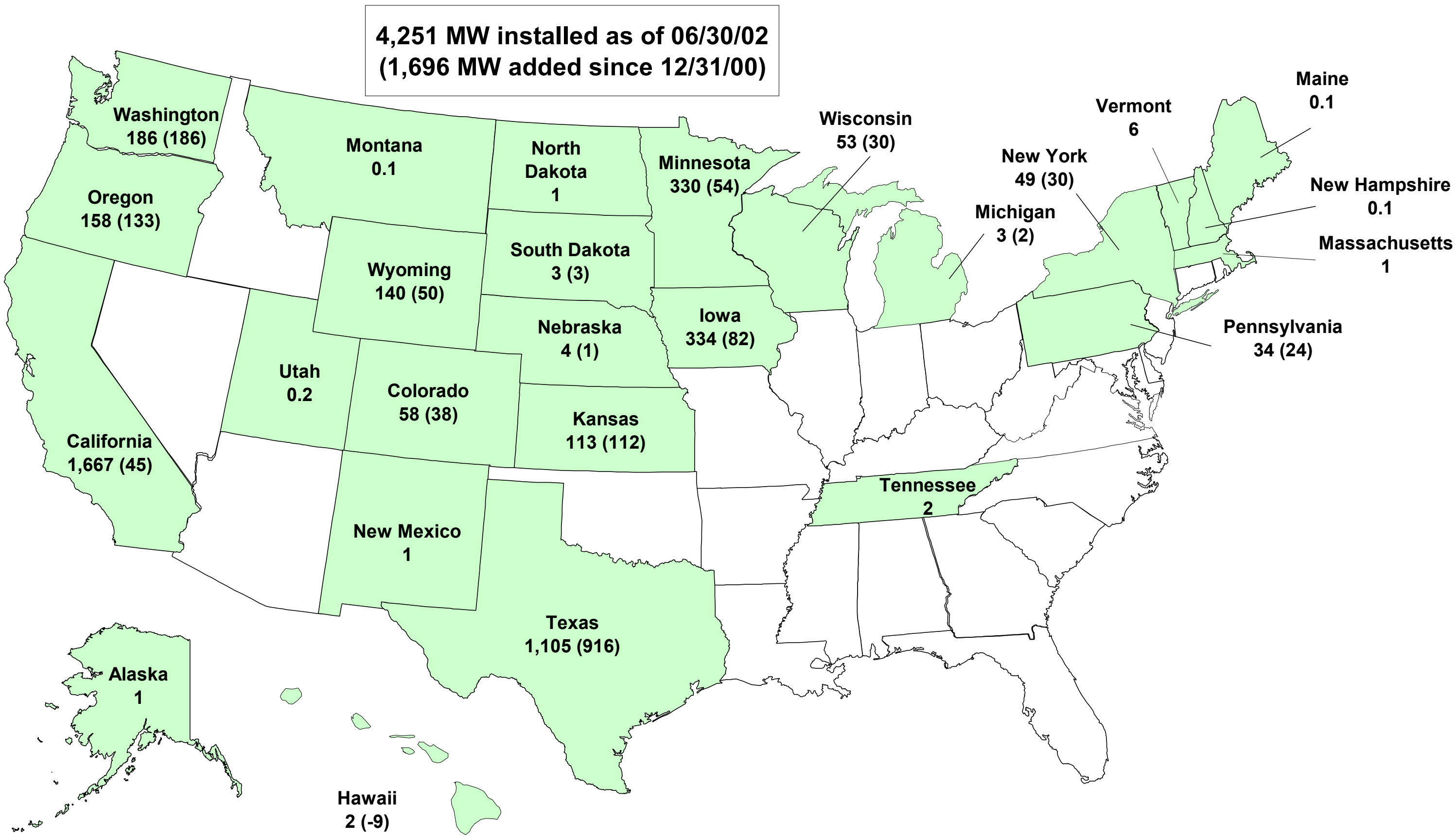


Figure 3: Installed Wind Capacity in the United States

Figure 4 shows installed utility-scale capacity by state, as well as incremental installed capacity since the end of 2000 (in parentheses). Despite little new wind development having occurred in California since the 1980's, that state continues to rank first in terms of installed capacity, with Texas close behind and likely to clinch the lead in the near future. Iowa and Minnesota rank 3rd and 4th respectively, followed by Washington and Oregon (who share the 300 MW Stateline wind project straddling the Columbia River).



Source: Windpower Monthly News Magazine

Figure 4: Installed Wind Capacity (MW) in the U.S. ***(parentheses indicate incremental capacity since 12/31/00)***

3.1.2 Market Growth Prospects

Growth (and the timing of growth) in the US wind power market is heavily driven by the federal production tax credit (PTC) and its expiration or reauthorization schedule. The PTC is a 1.5¢/kWh (adjusted for inflation, stands at 1.8¢/kWh in 2002) tax credit available for the first 10 years of a commercial wind project. The PTC expired at the end of 2001, and in March 2002 was reinstated retroactively for 2 years (i.e., wind projects online before 12/31/03 will be eligible for the 10-year credit). Unless the PTC is extended well in advance of its scheduled expiration, 2003 will likely be a strong year for US wind development, as developers rush to complete their projects before the year's end.

It is unclear how much additional utility-scale wind turbine capacity will be added in the US in the future, though growth prospects are reasonably strong. Table 5 presents two independent forecasts of US utility-scale wind power growth through 2005: the EIA reference case forecasts that 2,530 MW will be added between 2002 and 2005, while BTM (2001) forecasts 3,400 MW of incremental capacity over this 4-year period.

Table 5: Forecast of Annual US Wind Capacity Growth (MW)

	EIA Reference Case*	BTM (2001)
2002	970	800
2003	560	1,000
2004	450	800
2005	550	800
Total	**2,530**	**3,400**

*The EIA's AEO 2002 Reference Case assumes no PTC extension beyond 2001.

By 2020, the EIA reference case in Annual Energy Outlook 2002 (AEO 2002) forecasts 9,060 MW of installed wind capacity in the U.S., an annualized growth rate of 6.8% from 2000-2020 (note that this assumes no PTC extension beyond 2001). Assuming the PTC is extended through 2006, AEO 2002 forecasts 13,000 MW by 2020 (an increase of 4,000 MW due solely to the PTC extension). In a separate "High Renewable Energy Case," AEO 2002 forecasts 8,720 MW of installed wind by 2010 and 25,270 MW by 2020. This represents a 12.4% annualized growth rate from 2000-2020.

3.2 Drivers of Utility-Scale Wind Development in the United States

The major drivers of utility-scale wind energy development in the US include the federal production tax credit, 5-year accelerated depreciation, renewable portfolio standards, system-benefits charges, green power demand, and, increasingly, economics. Each of these drivers is briefly described below.

The Federal Production Tax Credit (PTC) has been a major driver of wind activity in the US. Originally implemented in the Energy Policy Act of 1992 as 1.5¢/kWh for the first 10 years of a project's life, the PTC is indexed to inflation and currently stands at 1.8¢/kWh in 2002. The PTC can lower the cost of wind-generated electricity by nearly 2¢/kWh. The PTC must periodically be re-authorized by Congress; the credit was allowed to expire at the end of 2001, but in March 2002 was re-instated retroactively through the end of 2003. Thus, any commercial wind project on line prior to December 31, 2003 is guaranteed to receive the PTC for 10 years (whether or not the PTC is extended beyond that date). Meanwhile, several bills currently before Congress include PTC extensions. The periodic expiration of the PTC has resulted in a boom/bust cycle for wind development in the U.S. (see the spikes in 1999 and 2001 in Figure 3 above), as developers rush to complete their projects ahead of these deadlines. Uncertainty over whether the PTC will be extended makes projecting wind installation trends into the future difficult.

5-Year Modified Accelerated Cost Recovery System (MACRS): The IRS tax code allows wind turbine equipment to be fully depreciated at an accelerated rate over a 5-year period. This rule provides an additional tax incentive to owners of wind power projects.

Renewable Portfolio Standard (RPS): An RPS requires all retail suppliers to include a minimum percentage (usually increasing over time) of eligible renewable energy in their products. In the U.S., 13 states have enacted some form of RPS policy (with varying effectiveness), and there have been several attempts to enact a federal RPS as well. Since an

RPS tends to favor the cheapest renewable energy technologies, wind power is a major beneficiary of this policy. This is evident in Texas, where an RPS that amounts to a 2000 MW renewable energy requirement by 2009 has triggered "the Texas wind rush:" more than 900 MW of wind power were installed in Texas alone during 2001.

System-Benefits Charges (SBC): Fourteen states have enacted SBC funds devoted to renewable energy. More than $3 billion earmarked for renewable energy will be raised over the next decade through these small charges on electricity bills. Once collected, a number of states are using these funds to provide direct financial incentives to wind power projects. To date, wind power has been one of the primary recipients of these funds in California, Pennsylvania, New York, New Jersey, and Oregon. Much of the wind development in the mid-Atlantic states over the past few years would likely not have occurred without the support of SBC funds (along with green power demand and the prospect of RPS policies in New Jersey and elsewhere).

Consumer Green Power Demand: Experience in California, Pennsylvania, and elsewhere has shown that some consumers are willing to voluntarily pay a bit more for electricity generated from clean, renewable energy resources (so-called "green power"). Wind power has benefited from green power demand, particularly in the Mid-Atlantic region, where several wind farms in Pennsylvania are currently devoted to satisfying green power demand. Large customers (commercial, institutional, and governmental) have shown particularly strong interest in supporting green power, often the result of executive or legislative activity (in the case of governmental purchases). Nonetheless, the total demand for wind-generated electricity from these voluntary green power markets on a nationwide basis does not yet exceed 500 MW.

Economics: Wind project development in the US is largely driven by federal tax incentive policies (PTC and accelerated depreciation), and state incentives (SBC) and mandates (RPS). Increasingly, however, wind power is able to compete (and occasionally win) head-to-head with other forms of generation on the basis of cost alone (including the impact of the PTC and accelerated depreciation). The economics of wind is detailed further in later sections of this chapter. At a cost of as low as 2.5¢/kWh, however, wind power is now able to compete with natural gas generation in some parts of the US. This trend is likely to continue into the future, at least as long as the PTC remains in place.

3.3 Typical Turbine and Project Sizes

3.3.1 Typical Turbine Size

Table 2 showed that the average size of utility-scale turbines installed in the U.S. in 2000 was 686 kW, up from 327 kW in 1995. Data presented below in Table 6 suggests that this number increased to 893 kW in 2001. Half of all new installed capacity in 2001 featured MW-class turbines (see Table 6 below). This upscaling of turbine sizes is likely to continue, and many believe that onshore wind applications will in the future feature turbines with an average size of 1.5 MW each (offshore wind applications will utilize turbines in the 3-5 MW range). It is our understanding that Wind Sail would pursue much smaller turbines, which are generally not favored in utility-scale wind applications.

Table 3 (earlier) showed that the cumulative average turbine size has only increased from 118 kW in 1995 to 161 kW in 2000. This is because much of the installed wind capacity in the US (and California in particular) is from the 1980s (when individual turbines were quite small), and relatively little capacity was installed during the late 1990s. However, with a banner development year in 2001 featuring large MW-class turbines, this average likely jumped significantly in 2001.

3.3.2 Typical Project Size

Table 6 lists 20 projects that came on line in 2001, totaling 1,670 MW. These projects represent 99% of all the wind capacity installed in the U.S. in 2001; the remaining 1% (<20 MW total) is comprised of a dozen or so "onesies" and "twosies" – small projects with just one or two turbines, most often installed in Minnesota to take advantage of a 1.5¢/kWh state production incentive for projects under 2 MW and sited on agricultural land. Excluding these small projects, the average project size installed in 2001 was 83.5 MW. While project sizes range considerably, there is a trend towards larger projects, especially in the Mid-Western and Western states where land constraints are less significant. Projects ranging from 20-100 MW in size are becoming standard.

Table 6: US Wind Projects Developed in 2001 ***(sorted by project size in descending order)***

Project Name	State	Project Size (MW)	# of Turbines	Turbine Size (MW)	Turbine Manufacturer
King Mountain	TX	278.2	214	1.3	Bonus
Stateline	WA, OR	262	397	0.66	Vestas
Desert Sky	TX	160.5	107	1.5	GE Wind
Woodward Mountain	TX	159.7	242	0.66	Vestas
Trent Mesa	TX	150	100	1.5	GE Wind
Gray County	KS	112.2	170	0.66	Vestas
Indian Mesa	TX	82.5	125	0.66	Vestas
Top of Iowa	IA	80.1	89	0.9	NEG Micon
Llano Estacado	TX	80	80	1	Mitsubishi
MountainView	CA	66.6	111	0.6	Mitsubishi
Rock River I	WY	50	50	1	Mitsubishi
Fenner	NY	30	20	1.5	GE Wind
Montfort	WI	30	20	1.5	GE Wind
Peetz Table	CO	29.7	33	0.9	Nordex
Condon	OR	24.6	41	0.6	Mitsubishi
Klondike	OR	24	16	1.5	GE Wind
Ruthton	MN	15.84	24	0.66	Vestas
Mill Run	PA	15	10	1.5	GE Wind
Ponnequin III	CO	9.9	15	0.66	Vestas
Somerset	PA	9	6	1.5	GE Wind
Total		**1,670 MW**	**1,870**	**0.893**	

3.4 Installed Costs

3.4.1 Data on Installed Costs of Wind Projects

The installed cost of utility-scale wind projects in the US has declined dramatically in the past twenty years. In the early 1980s, Kenetech reportedly installed 100 kW machines at Altamont at a price of $2,200/kW, and Zond's (later Enron Wind and now GE Wind) first project in 1981 was completed at an installed cost of $4,000/kW (EPRI 2001).

Today, a common rule of thumb is that utility-scale turbines (if installed as part of a larger wind farm) can be installed at a total cost of $1,000/kW. Of course, actual installed costs can vary significantly from project to project, depending on project size, strength of the dollar (most turbines are manufactured overseas), site terrain and location, ease of interconnection, and other factors. Thus, a range of installed costs is more appropriate. EPRI's Technical Assessment Guide (TAG) – a widely cited source for wind project cost data – identifies a range of installed costs from $1,600/kW for a single turbine project to $1,000/kW for projects over 50 MW, and notes that recent projects in the U.S. are towards the lower end of this range (EPRI 2001).

Data on actual installed costs for specific projects is hard to come by, but three sources are reported below: (1) TVP data, (2) wind plant sales prices, and (3) the Energy NorthWest wind project. These data generally support the $1,000/kW installed cost for larger wind projects in the US.

- **TVP Data.** DOE's Wind Turbine Verification Program (TVP) monitors the development and operation of six wind projects across the United States. Table 7 shows installed costs of five of these projects.

Table 7: Installed Costs from DOE Turbine Verification Program

Project	State	MW	$/kW	Year
Central & South West	TX	6.6	1,130	1995
Green Mountain	VT	6.05	1,800	1996
Wisconsin Low Wind Speed Turbine	WI	1.2	1,670	1998
Algona	IA	2.25	1,230	1998
Springview	NE	1.5	1,380	1998

Note that these are all small projects, and fairly old (in terms of how quickly the market is evolving). Even so, two of the projects stand out as being particularly expensive. The Green Mountain project's installed cost of $1,800/kW is reportedly the result of:

- higher-than-normal permitting costs (which would have been lower on a $/kW basis were the project larger)
- relatively high pre-construction costs (e.g., clearing trees and building roads)
- cold weather features made the turbines more expensive than normal
- this was Green Mountain's first wind project (learning curve)

At $1,670/kW, the Wisconsin Low Wind Speed Turbine project was expensive due to delays in the project caused primarily by two successive bankruptcies of turbine suppliers (as well as a learning curve – this was the utility's first wind project). The original turbine supplier, Kenetech, went bankrupt in 1996, and the replacement supplier, Tacke, went bankrupt in 1997 during construction. Enron Wind subsequently purchased Tacke and completed the project.

- **Wind Project Sales Prices.** In addition to the TVP data on actual project costs, we have data on the sales price of 6 projects that were built and sold in 2001 or 2002. Table 8 summarizes this information. With the exception of the 66.6 MW MountainView project (whose high price reflects its lucrative power purchase agreement signed at the height of the California electricity crisis) and the 15 MW Mill Run and 9 MW Somerset projects (sold jointly as a 24 MW project, but still much smaller than the other listed projects), the other projects' *sales prices* are approaching $1,000/kW, and one project (Klondike) was sold for far less than that ($700/kW). Note that these turnkey sales prices are likely to be higher (perhaps significantly so, particularly in the case of MountainView) than actual installed costs, as an operating project is not as risky as a project in development, and the developer will require adequate compensation for having taken on the development risk. Thus, while it's impossible to say for sure, it is likely that each project's installed cost is well below $1,000/kW.

Table 8: Sale Price of Six Projects Recently Built and Sold

Project	State	MW	$/kW	Year
Confidential		>50	1,125	2001
Confidential		<25	1,238	2001
Llano Estacado	TX	80	1,033	2001
Desert Sky	TX	160.5	1,094	2001
MountainView	CA	66.6	1,540	2002
Klondike	OR	24	700	2002

- **Energy NorthWest Project Cost.** We also have information on the projected installed costs of a 48.1 MW wind project currently under construction in Washington State. Energy NorthWest, the project owner, is a publicly owned utility that issued revenue bonds to finance the project. The bond prospectus reveals that the cost of the turbines and towers comes to $550/kW, the full EPC contract (i.e., turbine plus installation costs) comes to $877/kW, and the all-in costs (including EPC, contingencies, T&D and interconnections, Energy Northwest development and bond issuance costs, and indemnity contract cost) comes to $1,189/kW (Wiser 2001).

A final source of installed cost data comes from turbine orders. Many of the Vestas turbines (660 kW) installed last year (see Table 6 above) were purchased in bulk by wind developer and project owner Florida Power & Light (FPL). FPL reportedly placed a 700-turbine order with Vestas in 2000, and due to the sizable purchase received very low turbine prices. For example, the January 2001 issue of *WindPower Monthly* states: "Last month, Vestas of Denmark, the world's largest wind turbine manufacturer, quoted an option on additional machines for a large American order at a price a fraction above $447/kW. This implies complete wind farms can be built for around $650/kW, even if no further savings are made in balance of plant costs." Note that FPL reportedly sourced towers locally, instead of purchasing from Vestas; hence, the quoted price of $447/kW likely represents all turbine equipment except the tower.

In conclusion, to enter the utility-scale wind market in the US, all else equal, Wind Sail would need to offer total project costs of at or around $1000/kW. The wind turbines alone will likely need to be priced at or below $600/kW.

3.4.2 Breakdown of Installed Costs

Tables 9 and 10 estimate the percentage of total installed costs spent on various project elements. Table 9 reflects project-level categorizations, while Table 10 focuses more acutely on turbine components. Potential items of interest to Wind Sail (which is contemplating a "towerless," gearless turbine) include the fact that towers make up 10-13% of total installed costs, while gearboxes reportedly account for as much as 17% of installed costs.

Table 9: Typical Project Capital Cost Elements

	% of Total Investment Costs
Turbines	49%
Construction	22%
Towers (tubular steel)	10%
Interest During Construction	4%
Interconnect/Substation	4%
Development Activity	4%
Financing & Legal Fees	3%
Design & Engineering	2%
Land Transportation	2%
Total	100%

Source: EPRI 2001

Table 10: Typical Turbine Capital Cost Elements

	% of Total Investment Costs
Machine frame including ring	7%
Blades	14%
Hub including main shaft	6%
Gear including clutch	17%
Generator/controller	9%
Tower including painting	13%
Hydraulics including hoses	3%
Yaw gear	2%
Nacelle cover	4%
Insulation/cables, etc.	3%
Estimated assembly cost	3%
Total machine cost	**79%**
Civil works, infrastructure, and grid connection	**21%**
Total investment cost	100%

Source: Lako 2002

3.5 O&M Costs

3.5.1 O&M at the Project or Turbine Level

Just as $1,000/kW has become a rough rule of thumb for installed costs, 1¢/kWh has become a rule of thumb for utility-scale wind turbine O&M costs. As with installed costs, however, O&M costs vary from project to project due to a number of factors, perhaps most notably project size.

The 1997 version of EPRI's Technical Assessment Guide (TAG) estimates that – at that time – annual O&M costs ranged from **0.7¢-1.2¢/kWh** for a 25 MW project comprised of 500 kW turbines (EPRI 1997). A more recent update of EPRI TAG identifies O&M at $32.71/kW for a 1 MW wind plant and $19.32/kW for a 200 MW wind plant (EPRI 2001). At a 35% capacity factor these are equivalent to **1.0¢/kWh** and **0.63¢/kWh**, respectively.

A 1997 report from the National Wind Coordinating Committee estimates that maintenance costs for modern wind turbines are 1¢/kWh or less (Chapman 1997). Using a value of **0.9¢/kWh**, this document breaks O&M down as follows:

- unscheduled maintenance (0.68¢/kWh or 75% of total O&M),
- preventive maintenance (0.18¢/kWh or 20% of total O&M),
- major overhauls, on a levelized replacement cost basis (0.04¢/kWh or 5% of total O&M).

In contrast, a recent report presented at AWEA's WINDPOWER 2002 conference estimates that for projects consisting of large (2 MW) turbines, unscheduled maintenance accounts for only 52% of O&M costs, scheduled maintenance accounts for 39%, and the remaining 9% is for operations and reporting (Vachon 2002).

This same report estimates that O&M costs are roughly **1¢/kWh** when levelized over 20 years. Specifically, O&M starts off at roughly 0.6¢/kWh for the first 3 years (assuming 3-year warranty), and then increases more or less linearly to roughly 2¢/kWh by year 20. These numbers include both scheduled and unscheduled maintenance costs (both escalating at a 2.5% inflation rate), but neglect lost revenue opportunities, due to the fact that the wind industry has been able to achieve rapid repair times by swapping out parts rather than repairing or rebuilding on site. In addition, costly failures of mechanical components tend to occur slowly, thereby allowing time to plan component replacement during scheduled outages (Vachon 2002).

EPRI (2002) confirms this assertion, by noting that the availability of utility-scale turbines in California has only been marginally impacted by widely reported performance problems over the years, because industry has worked to minimize down time by swapping out parts. One potential implication of this approach for Wind Sail is that its anticipated low-maintenance attributes may not provide much of a competitive advantage in the utility-scale segment of the market.

Finally, the bond prospectus for Energy Northwest's 48 MW Nine Canyon wind project indicates relatively high O&M costs of 1.4¢/kWh by the project's third year of operation, as shown in Table 11. This may be due to a conservative estimate of O&M costs.

Table 11: Energy NorthWest Project O&M Costs ($/MWh)

Costs	2004	2005	2006	2007
Fixed Operating Costs	8.7	11.3	11.6	11.9
Variable Operating Costs	0.6	2.7	2.8	2.9
Total Operating Costs	**9.3**	**14.0**	**14.4**	**14.8**

Source: Wiser 2001

3.5.2 O&M at the Component Level

Tables 12, 13, and 14 provide a sense of which turbine components require the most O&M, both in terms of frequency of component failure (Table 12) and magnitude of maintenance or replacement cost (Tables 13 and 14). Note that Tables 13 and 14 are in year 2000 Euro-currency units; with the Euro now roughly at parity with the dollar, a direct one-to-one translation from Euros to dollars will give a rough idea of costs in dollar terms.

Table 12: Estimates of Mean Time Between Failure (MTBF) for Key Mechanical Components of Mature Turbines

Component	Components per Turbine	MTBF = Mean Life (Years)
Gearbox	1	18
Generator	1	15
Blade	3	40+
Yaw Drive Motor	2-4	22
Yaw Drive Pinions	2-4	13
Yaw Bearing/Sliders	1	25
Hydraulic Power Units	1	15
Hydraulic Actuators	1-3	13

Note: MTBF is assumed invariant with turbine size.

Source: Vachon 2002

Table 13: Replacement Cost for Major Components on 600 kW Turbines

	[Thousand €$_{2000}$]	[€$_{2000}$/kW]
Entire blade set	~100	~167
Individual blade	~36	~60
Gearbox	>50	>83
Generator	Up to 18	Up to 30

Source: Dresdner Kleinwort Wasserstein, January 2001 (based on data from Allianz).

Source: Lako 2002

Table 14 shows that gearbox maintenance is a major O&M expense, accounting for roughly a quarter of annual maintenance costs for a typical 600 kW turbine.

Table 14: Estimated Maintenance Cost Over 15 Years for a 600 kW Turbine

	Cost over 15 years [Thousand $€_{2000}$]	Annual costs [$€_{2000}$/kW/a]
Maintenance including consumables	54	6.0
Oil change	15	1.7
Blade maintenance	33	3.7
Gearbox maintenance	51	5.7
Generator maintenance	10	1.1
Other	23	2.6
Insurance	41	4.6
Total	228	25.0

Source: Dresdner Kleinwort Wasserstein, January 2001 (based on data from Allianz).

Source: Lako 2002

Vachon (2002) reports that crane costs account for nearly half of total unscheduled maintenance costs, and are a function of both height and lift. For 20-25 ton cranes, the estimated 4-day lease costs (in North America) are roughly $60,000 for a 50m lift height, increasing to $70,000 for a 60m lift height. For 60-65 ton cranes, estimated 4-day lease costs are $138,000 for a 62m lift height, increasing to $170,000 for an 82m lift height (Vachon 2002). Several turbine manufacturers are now incorporating cranes directly into their nacelles/towers to ease maintenance of large turbines, particularly at offshore sites.

3.6 Overall Costs and Power Sales Prices

Ultimately, the various factors described above – project and turbine size, installed costs, and O&M costs – will, along with expected return on investment and capacity factors, determine the revenue requirements of a project. This will, in turn, dictate the price of a power sales agreement that a project requires to make the project profitable.

Nearly all utility-scale wind projects in the US require 10-30 year power sales agreements that will provide an assured revenue stream for the project's output at a price dictated in advance. Table 15 presents the key terms of 22 power sales agreements totaling 1,390 MW. This represents half of the utility-scale wind power capacity installed between 1998 and 2001 in the US, and one-third of total installed wind capacity in the United States as of the end of 2001. The contracts are sorted by commercial operation date (actual or expected). The contracts provide critical information about the effective cost of wind power for a utility buyer, and the price that Wind Sail would need to be able to supply to be competitive in this market segment.

To compare contract prices on a normalized basis, we levelized the price stream of each contract over a 25-year period according to the following assumptions:

- Contracts with terms of less than 25 years earn a fixed $30/MWh for their output once the contract term has expired.
- Contracts with options for extension (controlled by the buyer) will not be extended, and the project will simply earn a fixed $30/MWh once the initial contract term has expired.
- 3% inflation rate (all prices are in nominal terms)
- 10% discount rate

Results are presented in the final column of Table 15. The normalized 25-year contract prices in this sample range from a low of $25.5/MWh to a high of $71.6/MWh, with the capacity-weighted average price at **$38.5/MWh**. Note that all of these projects receive the 10-year federal production tax credit (1.8¢/kWh in 2002), which in most cases is built into their contract price.

Table 15: Project Economics

Achieved Commercial Operation	Contract Term (Years)	Project Capacity (MW)	Project Capacity Factor	25-Year Levelized Price (nominal $/MWh)
1998	30.0	~100	37.3%	31.5
1998	30.0	~25	34.5%	59.5
1999	25.0	~100	37.3%	30.7
1999	33.0	~10	31.4%	49.4
1999	15.0	~25	40.2%	42.3
1999	20.0	~75	40.6%	28.3
1999	20.0	~75	29.4%	50.4
1999	20.0	~100	N/A	43.7
2000	20.0	~25	41.9%	38.3
2000	10.0	~25	27.4%	49.5
2001	10.0	~25	23.0%	71.6
2001	15.0	~25	26.9%	38.6
2001	20.0	~10	30.4%	43.0
2001	20.0	~10	33.5%	43.0
2001	20.0	~50	36.9%	35.1
2001	10.0	~75	38.3%	49.3
2001	15.0	~75	37.8%	26.4
2001	20.0	~50	25.6%	62.5
2001	25.0	>100	34.1%	25.5
2002	11.5	~50	N/A	47.6
2002	11.5	~75	N/A	47.6
2003	17.0	~75	30.7%	48.4
		Total=1,390		**Wgtd Avg=38.5**

With the PTC, it appears as if Wind Sail would need to be able to supply power at under 4¢/kWh in order to be competitive.

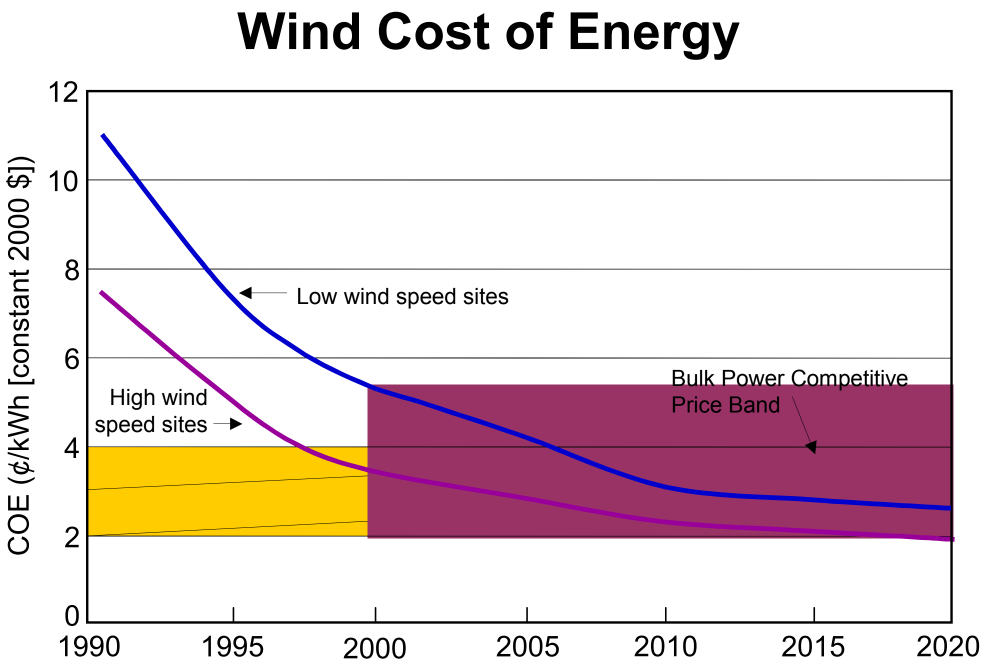
3.7 Capacity Factors and Project Performance

Based on the data presented above, project capacity factors – a function of wind resource – are revealed to be as low as 23% and as high as 42%, and are the major determinant of contract prices. (Of the remaining three variables shown in the table – commercial operation date, contract term, and project size – only project size exhibits a meaningful relationship with contract price; commercial operation date and contract term appear to have little bearing on price).

Though not shown in Table 15, turbine availability (i.e., the percentage of time that a turbine is *available* to generate electricity were the wind to be sufficient) is typically in the vicinity of 98%, and is generally guaranteed by the manufacturer to be at least 95% for the first 2-5 years of the turbine's life, depending on warranty arrangements (Dunlop 2001). This implies that utility-scale wind turbines in the US have very little "downtime," with scheduled and unscheduled maintenance typically occurring during times in which the wind is not blowing. Wind Sail's potential maintenance advantages may therefore not be deemed particularly important in the utility-scale market segment.

3.8 Cost Projections

Figure 5 shows NREL projections of future reductions in the levelized cost of electricity from utility-scale wind turbine technology (note that these estimates do not include the value of the 1.8¢/kWh federal production tax credit). According to this figure, wind is projected to become cost competitive – i.e., without any subsidy – with bulk power in the next 5-10 years. We note, however, that this projection appears aggressive. We estimate the current cost of wind power without the PTC to be ~5 cents/kWh, while NREL has pegged that number at ~4 cents/kWh.



Source: NREL January 2002

Figure 5: Projected Cost of Wind Energy

Dunlop (2001) estimates that the per-MW cost of wind turbines has declined by 3%-5% in recent years. He cites Moore's Law – a rule-of-thumb from the semiconductor industry that predicts that the performance/price ratio of computer chips doubles every 18 months – as potentially having an application to the wind turbine industry. In particular, since 1980 the size of turbines has doubled every four years, with every doubling in size bringing a 15% reduction in the per-kWh cost of the turbines (Dunlop 2001).

Lako (2002) looks at the implications of doubling cumulative installed capacity rather than turbine size. Cost reductions that are driven by improvements in manufacturing processes often proceed along a path known as a "learning curve". The "progress ratio" that describes the curve estimates the percentage cost decline for each doubling in manufactured capacity. For example, a progress ratio of 0.8 means that with each doubling of cumulative capacity, costs should decline by 1.0-0.80, or 20%.

While progress ratios for photovoltaics are often found to be on the order of 0.80, Lako (2002) observes that progress ratios for wind turbines tend to be higher, ranging from 0.90-0.98, depending on the turbine component. Perhaps not surprisingly, most potential for cost reductions comes from the rotor and nacelle (i.e., everything on top of the tower), which is estimated to have a progress ratio of 0.90. The progress ratio for the tower itself is 0.96, while "civil work, insfrastructure, and grid connection" is estimated to have a progress ratio of 0.98. Factors driving these rather high (i.e., modest potential for cost reduction) progress ratios are:

- the advanced state of current wind turbines with capacities 0.6 to 2.5 MW,
- limited potential for further up-scaling,
- limited cost reduction potential for towers (which are often sourced locally).

These three limiting factors (at least 2 of which do not apply to anticipated Wind Sail technology) suggest that future cost reductions for HAWTs may be somewhat more muted than they have been in the past (as consistent with Figure 5 above from NREL), or than Dunlop (2001) anticipates for the future. However, as a relatively immature technology, VAWTs are likely to have lower progress ratios than HAWTs, and therefore greater potential for future cost reductions through increased R&D and manufacturing volume.

3.9 Turbine Scaling Issues

The different cost trajectories pictured in Figure 6 reveal that cost reductions in HAWTs have been driven as much (or more) by upscaling of turbine size as they have by mass production. Specifically, the figure shows that larger turbines are far less costly than smaller ones, and that – within each turbine size category – cost reductions have occurred through time.

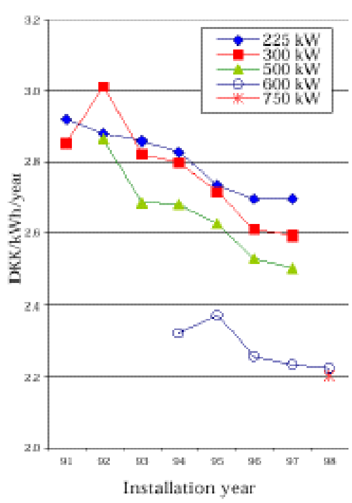


Figure 2.6 *Specific investment defined as ex-works Danish turbine price divided by annual production; roughness class 1; list prices of leading manufacturers (DKK$_{1999}$)*

Source: Wind power in Denmark. Technologies, policies and results. September 1999.

Source: Lako 2002

Figure 6: Cost Reductions Across Different Turbine Sizes

With 2+ MW turbines currently in production for on- and offshore wind projects, and 3+ MW turbines in near-term development for offshore applications (with 5 MW turbines in the planning stages), will this trend continue?

One of the main issues regarding further up-scaling of turbine size is the massive amount of weight that needs to be supported by ever-taller (= stronger = more expensive) towers. Lako (2002) examines the weight of the rotor and nacelle relative to turbine capacity and swept area for sub-MW- and MW-class turbines across six different turbine manufacturers who offer both classes. The average weight/capacity ratio (kg/kW) of sub-MW turbines is 53.7, compared to 56.2 for MW-class turbines. The respective weight/swept area ratios are 21.7 and 26.5.

While the 600-900 kW class of turbines exhibit the lowest weight/capacity and weight/swept area ratios, this does not automatically mean that this size range is optimal. A 1997 BTM Consult ApS document points out that higher towers usually translate into a better wind regime, while larger swept area equates to increased power output, meaning that on a weight/kWh basis, there is very little difference between sub-MW- and MW-class turbines (Ohlenschlaeger 1997). Although the cost/kW was slightly higher for the MW machines, the cost per generated kWh is almost the same as, or even less than, the smaller machines. Of course, the largest turbine examined in this document was only 1.65 MW (large at the time); whether this relationship holds for 3+ MW HAWTs remains to be seen.

Vachon (2002) reports that O&M costs for larger turbines (2 MW) are slightly lower (especially in later years) than for smaller turbines (600-750 kW). Even though cranes and parts are substantially more costly for large turbines, there are fewer total parts that fail (for a given project size). For example, there are only 10 generators that can fail in a 20 MW project consisting of 2 MW turbines, compared to 20 generators that can fail in a 20 MW project consisting of 1 MW turbines.

On the other hand, when a single generator fails in the former case, the project has lost 10% of its generating capacity, whereas when a single generator fails in the latter case, only 5% of total capacity is down. EPRI (2001) also points out that larger turbines have seen less operating experience, and are more challenging to erect in complex terrain and adverse weather conditions, perhaps making them riskier than time-tested smaller models (e.g., the Vestas 660 kW).

Overall, it is not clear when the current trend towards larger turbine sizes will stop. Many analysts believe that onshore applications are unlikely to trend towards turbines greater than 2 MW in size, if for no other reason than the challenges in transporting larger machines (and their massive towers) to project sites. Offshore turbine applications, meanwhile, may trend upwards of 5 MW.

3.10 The Competition: Turbine Manufacturers, Market Shares, Technology, and Profitability

3.10.1 Turbine Manufacturers Active in the US

The market for utility scale HAWTs is competitive. As shown in Table 16, six utility-scale turbine manufacturers were present in the US market from 1999-2001, with two in particular – Vestas and Enron Wind (now GE Wind) – dominating the market.

Table 16: Installed Capacity in US (1999-2001)

	MW	US Market Share
Vestas	822	31%
Enron/Zond	811	31%
NEG Micon	418	16%
Mitsubishi	281	11%
Bonus	278	11%
Nordex	24	1%
Total	2,634	100%

In addition to these stalwarts, other players to watch in the coming years include:

- **Gamesa Eólica** – The 2nd largest turbine manufacturer in the world, Gamesa turbines have so far been limited mostly to the Iberian Peninsula (the company is based is Spain) due to a restrictive licensing agreement with Vestas, who owned 40% of Gamesa. Within the past year, however, Vestas has sold its stake in Gamesa, thereby allowing Gamesa to look to other markets, including the U.S. (where it is rumored to be partnering with at least one developer).
- **The Wind Turbine Company** – With funding from the DOE and NREL, this Washington-based company has developed an innovative 2-blade downwind turbine that is light enough to be supported by very tall and lightweight towers (constructed from standard natural gas pipeline). This turbine has been extensively tested at NREL's wind test site, and a 500 kW commercial prototype is currently operating in southern California.
- **Lagerwey** – This Dutch company uses direct drive turbines (750 kW, 1.5 MW and 2 MW, see Figure 8), has just completed its first installation in North America (in Toronto), and is rumored to be mounting a challenge to GE Wind's patent on variable speed technology as it plans to enter the US market.

3.10.2 Technology

The major suppliers of utility-scale wind turbines in the US are all using the same basic turbine configuration: upwind, 3-bladed horizontal axis wind turbines. Variations in gearbox and generator configurations, however, are common. While details are not provided here, one point does deserve note: besides Lagerwey, at least 3 other European turbine manufacturers are developing direct drive technology for HAWTs. Enercon (from Germany) offers 4 different gearless turbines, ranging from 300 kW (see Figure 7) to 1.8 MW. Jeumont (from France, new to the wind industry) is testing a commercial prototype 750 kW direct drive turbine (see Figure 9). ABB has also been developing a direct drive generator for offshore use (Windformer), but has reportedly abandoned that effort. As illustrated by the figures below, the large-diameter generator necessitated by direct drive technology has led to unconventional nacelle configurations (though not necessarily unappealing – Enercon has marketed its characteristic egg-shaped nacelle as "organic" and in harmony with nature's sense of design).

Figure 7: Enercon 300 kW

Figure 8: Lagerwey 750 kW

Figure 9: Jeumont 750 kW (nacelle)

3.10.3 <u>Profit Margins</u>

The wind turbine manufacturing industry for utility-scale turbines appears to be very competitive with regard to price, with EBIT (Earnings Before Interest and Taxes) margins low and ranging from 4%-15% (Dunlop 2001). Where a company falls within this range seems to depend partly on its size: Vestas and Gamesa, the two largest wind turbine manufacturers in the world, enjoy EBIT margins of 11-15%, while smaller manufacturers like Nordex and NEG Micon have EBIT margins of only 4-6%. While no turbine manufacturer posts a price list, and there is anecdotal evidence that price discrimination among clients does occur, it appears that NEG Micon is selling turbines at a 15% discount to Vestas' turbines (the market leader), likely in an attempt to gain market share (particularly following its recent gearbox problems, which almost bankrupted the company). This could account for a portion of its lower operating margins relative to Vestas (Dunlop 2001).

3.11 Conclusions

The market for utility-scale wind turbines in the US is potentially quite large, yet is also quite competitive and perhaps unfriendly to newcomers utilizing new technology (witness the trials and tribulations of The Wind Turbine Company). This market does not in general seem to be a promising fit for anticipated Wind Sail technology for a number of reasons:

- Wind Sail turbines are likely to be too small to compete (see Section 3.3).
- Wind Sail's anticipated maintenance benefits are not critical for this market segment (see Section 3.5).
- The current market is very competitive in terms of total costs and profitability (see Sections 3.6 and 3.10).
- Turbine manufacturers have been able to develop direct drive technology in a HAWT design (see Section 3.10).

In addition, Wind Sail would need to overcome the stigma of VAWTs, which is perhaps more engrained within the utility-scale sector than in any other.

One potential niche that Wind Sail might seek to exploit within this sector involves "infilling" at existing wind farms by siting low-height VAWTs interspersed among the taller HAWTs to capture unused wind resources. The potential to take advantage of pre-existing infrastructure (e.g., sub-stations, transmission access, roads, etc.) as well as a proven wind resource (at least at 50 meters) is what makes this strategy potentially low-cost and somewhat intriguing. It is not clear, however, what potential this strategy holds, especially where land constraints do not hinder the use of larger and more cost-effective turbines. We note that at least two other VAWT manufacturers (Wind Harvest Company and TMA, see Section 4.5.2) seem to be pursuing this approach, though few installations of this type have yet occurred. Projects of this type are most likely in California, a state that is facing serious constraints on finding new wind sites, but projects would likely still need to compete with new MW-class wind turbines at 4¢/kWh or less.

4. Small-Scale Wind Turbine Markets in the U.S. and Abroad

This chapter primarily covers the small-scale wind turbine market in the U.S., with some information provided on overseas markets as well. Again, for the purposes of this report, we define "small-scale" to include turbines of 100 kW or less that are used primarily in customer-sited applications, including residential or commercial grid-connected, off-grid battery charging, and village power hybrid applications. While the size threshold is somewhat arbitrary, our understanding is that this size range (from <1kW to 100 kW) is consistent with the size range of potential turbines envisioned by Wind Sail. While most small-scale turbines are at the low end of this range, there is at least one U.S. manufacturer of a 100 kW turbine intended primarily for remote off-grid applications (Northern Power Systems),[2] and several manufacturers of 50 kW models (Atlantic Orient Corporation, Bergey Windpower).

When reading this chapter, Wind Sail should keep in mind that the quality and quantity of data pertaining to the small wind turbine market leaves much to be desired. We have attempted to piece together the various snippets of data that we have found in such a way so as to provide a broad picture that will be of value to Wind Sail as it contemplates entering this market. Our overview of the market, however, is limited by the quality and quantity of our data, and is by no means comprehensive. Furthermore, much of the data and market forecasts contained herein are self-reported from the small wind turbine industry, and so may be somewhat biased. Our main source of objective data comes from California – perhaps the largest market for small wind turbines in the U.S., yet also perhaps not a very representative market for the rest of the country or world.

Given these data limitations, we have not attempted to reach prescriptive findings or recommendations as to how Wind Sail should proceed. Instead, we offer the following as a reference document that compiles much (most?) of the relevant publicly available data on small wind turbines into one place. It is up to Wind Sail to interpret this data and draw its own conclusions.

4.1 Market Size and Potential

4.1.1 Current Market Size

A 1984-1989 market study of all known small wind turbine (SWT) manufacturers found that these companies had produced over 38,000 turbines totaling $3.8 million in annual sales (REFOCUS 2002). As of 1997, the global SWT market had grown to $24 million (REFOCUS 2002), and there were reportedly 55 small turbine manufacturers throughout the world (8 in the U.S. and 47 abroad), offering 146 different turbine models (23 U.S. and 123 international) (Forsyth 2000).[3] In the past 5 years, global SWT sales have reportedly grown at a rate of 40%/year (REFOCUS 2002, AWEA 2002a), which would place 2002 sales at around $130 million, while Whale (2001) reports that as of June 2001 the number of SWT manufacturers

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[2] Enercon (a German manufacturer of direct drive utility-scale wind turbines) is also rumored to be developing a 100 kW model.

[3] Reportedly, 37% of the international turbine models were either Russian or Chinese.

remains little changed, with more than 50 worldwide.[4] A recent private market study by the respected wind consulting firm Garrad Hassan projects that SWT sales have the potential to increase five-fold to well over $750 million by 2005 (REFOCUS 2002), implying that current sales are more on the order of $150 million/year, rather than the $130 million calculated above.

Taking the midpoint of $140 million/year and assuming (conservatively?) a per-watt cost of $5/W and an average SWT size of 1 kW implies that 28,000 SWT amounting to 28 MW of capacity will be sold in 2002.

Despite comprising only a small minority (~15%) of global SWT manufacturers and models, the U.S. SWT industry leads the market both at home and abroad in terms of the number and capacity of turbines produced (AWEA 2002a). For example, Southwest Windpower sold more than 10,000 turbines in 2001 (Southwest 2002) – i.e., approximately one-third of our 28,000 SWT estimate for 2002 – and Bergey Windpower claims to have achieved 80% market share in the 5-15 kW size range, with ~700 10 kW Excel-S turbines (i.e., 7 MW) installed as of 2001 (Bergey 2001a). Furthermore, while the U.S. is certainly not the world's largest market for SWT, Sagrillo (2002) points out that only two foreign SWT manufacturers – one European and one African – are represented by U.S. distributors, underscoring U.S. dominance of the market.

The leading market position of the U.S. SWT industry stands in contrast to other renewable energy technologies (e.g., large wind turbines and photovoltaics), which are dominated by foreign manufacturers. Furthermore, compared to the "homegrown" U.S. SWT industry, other renewable energy technologies are becoming increasingly controlled by large industrial interests with deep pockets and substantial political clout – e.g., BP Solar, Shell Solar, GE Wind, ABB (Reid 2001).[5] Ironically, despite its position as a global leader, the U.S. SWT industry has been unable to attract the same level of attention as other renewable technologies such as PV and large wind, and has in turn received less political and financial support than these other technologies, at least at the Federal level.

One outcome of political impotence is a relatively weak domestic market for SWT. While the market for SWT has recently been growing by 40% per year, and there are currently between 15-18 MW of SWT installed in the U.S., the largest markets remain overseas (AWEA 2002a). In 2001, the U.S. SWT industry sold 13,400 turbines, more than half of which were exported (AWEA 2002a). Southwest Windpower – the U.S. Export-Import Bank's 2002 Small Business Exporter of the Year – alone claims to have built 10,000 turbines in 2001 (again, half of which were exported, most of which are presumably under 1 kW in size), bringing its cumulative manufactured volume to more than 60,000 turbines since the company was formed in 1986 (Southwest 2002).[6]

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4 At the end of this chapter, we present data and web links for many of these manufacturers.

5 On the one hand, Wind Sail could interpret the fact that these big energy corporations are investing in PV and utility-scale wind but not small wind as a sign that the profitability of the SWT market is limited. On the other hand, the fact that the SWT market has survived in the face of deep-pocketed competition and relatively little political support may indicate underlying strength in the market.

6 Given Southwest's numbers, Whale's (2001) assertion that 60,000 small wind turbines have been manufactured in Western countries over the past 20 years seems conservative.

Many of these turbines are going to the developing world, where millions of people still lack access to electricity. Bergey (2000) calls the rural electrification of China the "world's largest market for small wind," and reports that 150,000 SWT have been installed to date in China, with more to come. Many of these SWT are very small and portable units (< 500 W) used primarily by nomadic herdsmen in Inner Mongolia.

While the off-grid market, particularly in developing countries, would appear to be the largest potential market for SWT, by nature it is difficult to find data on the size of this market. Data on grid-connected systems are relatively easier to find, though still spotty. In the U.S., Forsyth (2002) looked at 10 states that offer favorable policies for SWT and found 1,363 kW of grid-connected, net-metered SWT in place. This number appears to be fairly conservative, based on Mike Bergey's claim that his company alone has sold many times more grid-connected SWT systems domestically.

Given the relatively poor quality of national and international data on SWT that is publicly available, we will now take an in-depth look at the SWT market in California, which is arguably the largest and most favorable market for SWT in the U.S., and also provides some of the most complete and reliable data.

4.1.2 California's SWT Market

Table 17 provides historical data, as well as future projections, on the number and size of SWT operating in California's grid-connected, off-grid residential, and off-grid telecom markets. Data come from EPRI (2001b), and future projections are necessarily speculative. The grid-connected market is logically segmented into before and after the inception of the CEC's buy-down program in 1998 (more on the buy-down program below), with the off-grid markets structured similarly for comparison purposes (despite not being eligible for the buy-down).

Table 17: California's SWT Market

Market	Period Covered	# Turbines	Notes	Operating Experience
Grid-Connected	1990-1998	~100 total, not including sales from Jacobs	Ranging from 1-10 kW	Most turbines installed prior to CEC buy-down program are no longer in operation.
	Current	~150 turbines installed, >1 MW of capacity either installed or planned**	Expanding through CEC buy-down program	
	Future	300-500/year	Ranging from 400 W to 10 kW	
Off-Grid Residential	1972-1998	~2000 total	Rapid expansion with introduction of 300-400W turbines in 1990s (i.e., Southwest Windpower)	~50% of turbines installed in the 1970s and 1980s no longer in operation. Most turbines installed in 1990s still in operation.
	1999	~800 systems sold <500W, plus 75 systems from 1-10 kW	Not eligible for buy-down funds.	
	Future	250-400/year, mostly 400W	Not eligible for buy-down funds.	
Off-Grid Telecom	1990-1998	~80 total	Most <1 kW	Most still in operation
	Current	~75, most <1 kW	Expanding slowly; not eligible for buy-down	
	Future	250-400/year, mostly 400W	Same projection as for off-grid residential (i.e., a guess)	

*Source: EPRI 2001b, except ** from Brasil 2002 and Orta 2002*

Table 17 shows that, as expected, the off-grid market is larger (in number of units sold) than the grid-connected market, although off-grid applications tend to use smaller turbines of less than 1 kW – the market segment dominated by Southwest Windpower. Also of interest is that half of all SWT installed in the 1970s and 1980s, and many of the grid-connected SWTs installed in the 1990s, are no longer operational. While some of this poor performance history can be attributed to inferior turbine design and quality among certain (likely now defunct) manufacturers,[7] much of this phenomena is also maintenance related: a person relying on a SWT as the only source of electricity is likely to take better care of a turbine than someone who has grid power as a backup should the SWT fail (EPRI 2001b).

We'll now focus on the grid-connected segment of California's market, particularly since 1998, when the California Energy Commission (CEC) first implemented a "buy-down" program that offers $/W capital grants to buy down the capital cost of certain customer-sited renewable energy technologies, including photovoltaics (PV), small wind (<=10 kW), fuel cells using renewable fuels, and solar thermal electric technologies. The CEC initially budgeted $54 million for this program between 1998 and 2001; these funds have since been augmented to a total of roughly $100 million through 2002. From 2003-2007, funding for this program will likely be in excess of $24 million/year.

[7] Mike Bergey claims to be the sole survivor from among 45 competitors in the 1970s and 1980s (Bergey 2001a).

The CEC's program is by far the largest buy-down program in the nation. Similarly, customer response to this program – though lackluster during the first few years – has been much stronger than that seen in similar programs in other states. These factors make the CEC's buy-down program one of the best sources of data on both the number and actual installed costs of small wind turbines in the United States (with several caveats, discussed below in Section 4.4).

Note that historically, only wind turbines that did not exceed 10 kW in size were eligible for the CEC program.[8] Table 18 lists the 10 turbines that were eligible for the CEC program as of April 26, 2001 (i.e., the last time the list was updated). Only 3 manufacturers have qualified for the buy-down in California: Bergey, Southwest, and Wind Turbine Industries (i.e., the buyer of the Jacobs technology). These manufacturers are the only three to have met the CEC's eligibility requirements of (a) safety and performance certification (e.g., UL-listing), (b) successful operation for at least one year at a site with an average annual wind speed of 12 mph, and (c) a 5-year warranty.[9] Note that the Jacobs 10 kW model has since been discontinued by the manufacturer, leaving Bergey to dominate the upper end of the eligible range.

Table 18: SWT Eligible for the CEC's Buy-Down Program

Manufacturer	Model	Capacity (W)
Bergey Windpower	BWC XL.1	1,200
Bergey Windpower	BWC 1500	1,500
Bergey Windpower	BWC EXCEL	10,000
Southwest Windpower	AIR403	472
Southwest Windpower	Windseeker 502	500
Southwest Windpower	Windseeker 503	500
Southwest Windpower	Whisper H40	900
Southwest Windpower	Whisper H80	1,000
Southwest Windpower	175 (Whisper 3000)	3,000
Wind Turbine Industries	Jacobs 23-10**	10,000

***Production of the Jacobs 23-10 has been discontinued*

Between early 1998 and August 14, 2000, 26 wind turbines totaling 93 kW (i.e., average turbine size of 3.6 kW) had been installed at an average cost of just over $5/W. Another 25 turbines totaling 51 kW (i.e., average turbine size of 2.1 kW) were in development at an average cost of around $4.5/W (see Section 4.4 on SWT costs below and Figure 11 for more detailed information on installed SWT costs in California). In other words, 2.5 years after the start of the CEC's buy-down program, only 144 kW of small wind was either installed or being installed in California under this program (CEC 2000). The slow pace of reservations during the first few years CEC's buy-down program was the product of:

- ***Slow development of satisfactory inverter technology:*** Because SWTs typically operate at variable speeds (i.e., direct drive), the voltage of their output also varies, which causes problems for typical off-the-shelf inverters that are designed to handle a constant voltage.

[8] Starting in 2003, the CEC will allow wind turbines of up to 50 kW to qualify, in order to accommodate new products and coordinate more effectively with the CPUC's Self-Generation Program, which offers a buy-down to systems of between 30 kW and 1 MW.

[9] Note that of these three manufacturers, only Bergey offers a 5-year warranty as standard practice. The other two manufacturers must either have agreements with individual dealers/installers to extend their standard warranties to 5 years, or else the dealer/installer is shouldering the risk once the manufacturer's warranty expires.

One significant manufacturer did not have a CEC-approved inverter until January 2000. A second is still dissatisfied with current inverter technology (EPRI 2001b).

- ***Poor customer awareness/interest:*** The CEC's own market research showed that nearly two years after its inception, only 14% of residential and 9% of business customers in California were aware of the buy-down program (CEC 2000).
- ***Local zoning requirements:*** Most suburban zoning laws are antiquated and restrict the height of any structure to just 35 feet – the height that early fire engine ladders were able to reach. Since most manufacturers recommend that SWT be "flown" at double that height (or higher), zoning laws have presented a major barrier to the SWT market (EPRI 2001b). (Note: A VAWT situated on the ground or on top of a short tower may circumvent this market barrier).

By early June 2002, the amount of small wind capacity installed under the CEC's program had risen to 530 kW, with another 596 kW in development – i.e., 1,126 kW total (Orta 2002). As of October 2002 – i.e., 4.5 years after the inception of the CEC's buy-down program – roughly 150 small (<=10 kW) wind turbines have been installed under the program (Brasil 2002). While this is clearly a modest showing over the entire period, the recent acceleration in buy-down reservations for SWT holds promise for the future, and is due to a combination of factors:

- ***Electricity Crisis:*** California's electricity crisis highlighted the viability of self-generation as an alternative to utility power, and helped to publicize the CEC's buy-down program. Furthermore, the sharp increase in retail electricity rates resulting from the crisis has made self-generation options more economical. For example, at the height of the crisis in the winter of 2000/2001, Bergey reportedly sold over 100 home units in California in the first two months of 2001, compared with just six in all of 2000 and 12 in all of 1999 (when Y2K fears boosted sales) (AWEA 2001).
- ***Increased Buy-Down Incentive:*** In response to the crisis, the CEC increased its buy-down incentive from \$3/W to \$4.50/W in April 2001, while leaving the 50% cap in place.[10] Since SWT should theoretically cost less than \$6/W, this \$1.50/W increase in the buy-down level may not have had much of an effect on the SWT market (i.e., the 50% cap was likely binding both before and after the increase), other than perhaps to line the pockets of SWT installers (see Section 4.4 below).
- ***State Income Tax Credit:*** A 15% state income tax credit for solar and wind was enacted in September 2001.
- ***Permitting Legislation:*** In October 2001, California enacted legislation (AB 1207) requiring all local agencies of towns/counties to develop a permitting process for wind turbines, or else default to the statewide requirements, which are favorable to wind.

Despite these positive developments within the state (along with an expansion of net metering eligibility to include generators up to 1 MW in size), SWTs have not fared well under the CPUC's Self-Generation Program, which has been in place for almost two years and offers an incentive for wind turbines (sized between 30 kW and 1 MW) that was, prior to the CEC's 2003 revamp, identical to the CEC's buy-down – \$4.50/W up to 50% of installed costs. In fact,

[10] In 2003, the CEC revamped its buy-down for small wind to be \$2.50/W for the first 7.5 kW and \$1.50/W for the next 22.5 kW (i.e., up to 30 kW total), with no percentage caps. A performance-based incentive will be developed in the future for turbines between 30 and 50 kW.

through November 2002, *not a single wind turbine* had applied for funding under the CPUC's program.[11] A dearth of turbines at the low end of that size range could be one limiting factor.[12] Siting and permitting problems could be another, though as mentioned above, California has recently enacted legislation that should streamline the siting and permitting process. Whatever the reason behind the disparity, the fact that the CEC buy-down program has had some success with turbines of 10 kW or less, while the CPUC buy-down program has not funded a single turbine of 30 kW or more, may be particularly noteworthy for Wind Sail as it ponders what size turbine to pursue (at least for the U.S. market).

In light of California's aggressive incentives for small, grid-connected wind turbines – including both the CEC's buy-down program for turbines not exceeding 10 kW and the CPUC's buy-down program for turbines between 30 kW and 1 MW, the 15% state income tax credit, and the new legislation to facilitate siting and permitting – the limited number of small turbines that have been installed to date in California should raise a red flag as to the near-term market potential in the U.S. as a whole. In other words, it will be hard to find a state that offers a more favorable environment for grid-connected SWT than California, so the fact that only 150 small, grid-connected turbines have been installed in California over the past 4.5 years is disheartening. (Though the recent growth in demand is encouraging).

4.1.3 Market Growth Prospects

According to AWEA (2002a), the most recent publicly available market research for SWT was a DOE-sponsored A. D. Little study in 1981, which projected a domestic market potential of 3.8 million grid-connected systems. Assuming an average turbine capacity of 10 kW, this equates to 38,000 MW. AWEA (2002a) concludes that this study was conservative, because it excluded from consideration 100 counties with high population densities, but that have since installed SWT within their boundaries, proving the feasibility of doing so.

As noted above, the international wind consultancy Garrad Hassan recently concluded a private market study that projects that annual global SWT sales have the potential to increase five-fold from current levels to well over $750 million by 2005 (REFOCUS 2002). Unfortunately, we were unable to obtain data on the number of units or amount of capacity that $750 million represents, though if one (conservatively?) assumes a per-watt cost of $5/W and an average SWT size of 1 kW, $750 million equates to 150 MW of SWT capacity and 150,000 turbines annually by 2005.

In 2002, AWEA's small wind turbine committee released its own "roadmap" for the industry,[13] which includes projections of and goals for future growth. Table 19 projects that by 2020, there could be nearly 140,000 MW of SWT installed in the U.S. alone. Grid-connected homes are

[11] In contrast, over 25 MW of PV has applied for funding under the CPUC program, implying that customer awareness of the program is not a major issue (or alternatively, that PV dealers are much more aggressively marketing the program than are small wind dealers).
[12] The introduction of Bergey's 50 kW turbine has been delayed until 2003.
[13] The SWT committee consists of the major SWT manufacturers (chaired by Mike Bergey), as well as AWEA staff and consultants. Though an AWEA document, this roadmap was produced in conjunction with NREL, and can therefore likely be assumed to represent their best thinking on this topic as well.

projected to be the largest market by far, as the industry's long-term vision is of a major new category of home energy appliance (AWEA 2002a).[14]

Table 19: Market Potential for Small Wind Turbines in the United States in 2020

Market	Units	Avg Turbine Size (kW)	Total Capacity (MW)
Grid-Connected Homes*	15,100,000	7.5	113,250
Commercial Buildings	675,000	25	16,875
Public Facilities	160,000	50	8,000
Off-Grid Homes	150,000	3	450
Off-Grid Communities	200	250	50
Water Pumping	350,000	1	350
Telecommunications	2,000	2	4
Total	**16,437,200**	**8.5**	**138,979**

Source: AWEA 2002a

*AWEA estimates that there will be 43.2 million grid-connected homes sited on more than one-half acre of land in 2020, but excludes 65% of this gross amount to account for homes that are sited either: (a) in Class I (i.e., poor) wind resource areas, (b) close to airports or other sensitive areas, or (c) in communities with restrictive covenants or prohibitive zoning.

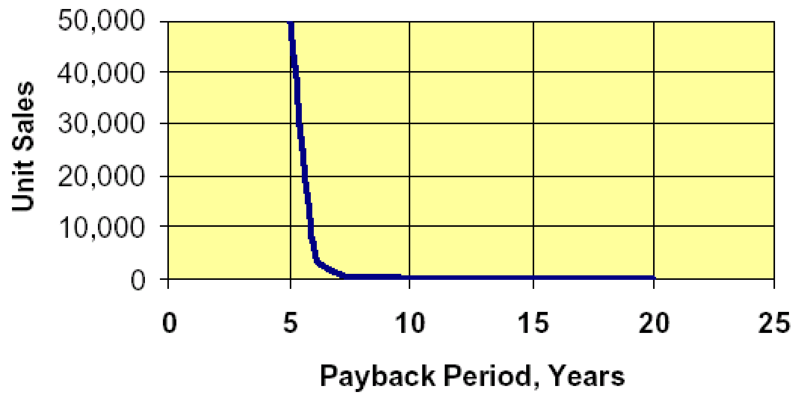
AWEA's goal is to reach 50,000 MW by 2020, more than a third of total estimated potential from Table 19, and equivalent to about 3% of U.S. electricity consumption, or 6-8% of residential electricity demand in 2020 (AWEA 2002a). Growing the domestic market from its current installed capacity of 15-18 MW to 50,000 MW in 2020 would require a doubling of the market each year for several years, followed by sustained sales growth in the range of 50%-55% per year. Under this scenario, the domestic SWT industry would reach annual sales of $1 billion and employ approximately 10,000 people in manufacturing, sales, installation, and support (AWEA 2002a).

Even though 2020 is still a ways away, AWEA's 50,000 MW goal is clearly very aggressive and should be considered a high-end projection, with the Garrad Hassan estimates (i.e., ~150 MW and 150,000 turbines annually by 2005 on a global basis) providing perhaps a more realistic (though perhaps still optimistic) future market assessment. Because they are detailed and broken out by application, however, the AWEA (2002a) numbers presented in Tables 19 (and 20) are interesting nonetheless.

To be setting goals as lofty as 50,000 MW by 2020, the SWT industry must feel that the market has explosive growth potential and, with state buy-down programs and other financial incentives, is on the cusp of a "tipping point." For example, Figure 10 (taken from a presentation by Mike Bergey) projects that as the payback period of a SWT approaches 5 years, turbine sales will shoot through the roof (Bergey 2001b).[15]

[14] Along these lines, note that Target was reportedly carrying Bergey's 1 kW wind turbine in its on-line catalog, though the author was unable to locate any wind turbines at www.target.com.

[15] Note that it is not clear whether Figure 10 represents Bergey's view of the market, or whether the figure is solely intended to be illustrative. Furthermore, we note that Bergey (2001b) also claims to have achieved a 5-year payback in California (given state incentives), yet we know that only a few hundred (i.e., not 50,000) SWTs have been installed or are planned in California, implying that development hinges on more than economics alone.



Source: Bergey 2001b

Figure 10: Effect of Payback Period on Unit Sales

In the off-grid market, Table 20 lists a potential for 150,000 SWT at off-grid homes. The EIA estimates that there are currently 200,000 off-grid homes in the U.S. (AWEA 2002a). In addition, AWEA (2002a) states that Alaska has 91 villages with a population of 42,000 that are powered by diesel generators. Singh (2001) places the number of remote villages in Alaska a bit higher at 175, and estimates that SWT could penetrate up to 130 MW, assuming that wind displaces half of the 259 MW of installed diesel capacity in Alaska as of 1988. Alaska already has three hybrid wind/diesel projects (Kotzebue, Wales, and St. Paul Island), with SWT's share of the generation ranging from 1/3 to 2/3. In addition, Canada has at least 500 MW of installed diesel in 300 remote communities. There are also a number of islands off of New England that may be suitable for small wind systems (Blanko et al. 2002).

AWEA's roadmap also provides projections for the potential size of foreign markets in 2010 and 2020. According to Table 20, foreign markets currently have an 80,000 MW potential, which will increase to 210,000 MW in 2020. Single homes installing very small turbines (average size of 400 W in 2020) make up about half of this market. Note that while the indicated turbine sizes are averages, that the largest average size is only 10 kW (for village power applications). As Wind Sail ponders what size turbine to produce, this table (and Table 19 for domestic applications) may provide some guidance as to where the industry thinks the market is going.

Table 20: Potential Markets for Small Wind Turbines in Foreign Countries

	2000			**2010**			**2020**		
System Type	Number (millions)	Avg Size (kW)	Total (MW)	Number (millions)	Avg Size (kW)	Total (MW)	Number (millions)	Avg Size (kW)	Total (MW)
Single Home	150.0	0.2	30,000	195.0	0.3	58,500	260.0	0.4	104,000
Village	3.8	10.0	38,000	4.9	10.0	49,000	6.6	10.0	66,000
Facilities	7.0	1.0	7,000	9.1	1.5	13,650	12.2	2.0	24,400
Misc	5.0	1.0	5,000	6.5	1.5	9,750	8.7	2.0	17,400
Total	**165.8**	**0.5**	**80,000**	**215.5**	**0.6**	**130,900**	**287.5**	**0.7**	**211,800**

Source: AWEA 2002a

While AWEA's roadmap does not break out foreign markets by country, Bergey (2000) notes that there is a World Bank project to install 30,000 hybrid systems in China, and another State Planning Development Commission (SDPC) program that proposes to install 35,000 5-10 kW wind/diesel systems in China. Both programs would build upon China's 190,000 existing SWTs (over 30,000 of which are apparently in need of renovation). Bergey (2000) also cites Chile as a potentially large market for wind/diesel systems (though he cites only thirty 3-40 kW wind/diesel systems that are planned).

The potential market for small wind in developing countries is clearly quite large: 1.5 billion people are without electricity on a worldwide basis. In China alone, despite incredibly aggressive efforts to electrify the countryside, 16,000 villages and 7 million households remain without electricity. China, in fact, has the largest small wind market in the world by a sizable margin, with 12,000 small wind systems manufactured in year 2000 alone, with most installed in Inner Mongolia. Most of these turbines are well under 1 kW in size, though larger, village electrification projects are under development. This market has been strongly supported by government policies and incentives.

Village electrification projects that combine wind and diesel generators have held particular interest for some time in developing country contexts. Another potential market for small wind is in electrical wind water pumping (mechanical wind pumps are already in significant use in some countries – with costs that reportedly range from $2500-$13000 each for larger systems) (Karekezi 2002, Karekezi and Kithyoma 2002, Harries 2002). Yet to date, few such systems have been installed.

While developing countries clearly hold promise as potentially large markets where SWT technology could be a cost-effective alternative to grid extension or alternative forms of generation (e.g., diesel or PV), one of the main barriers to SWT market expansion in developing countries is a severe lack of capital among the target market. As a result, capitalizing on these markets will most likely mean partnering with national or multinational governmental efforts, such as the World Bank and SDPC programs mentioned above. The historic dearth of U.S. tied aid has also put U.S. manufacturers at a disadvantage to European manufacturers, where tied aid is more common. Finally, a reliable maintenance and servicing infrastructure for small wind systems has often been difficult to develop.

4.2 Drivers of Market Growth

While off-grid applications are often least-cost alternatives and are therefore driven by economics alone, the grid-connected market in the U.S. is driven by a number of different factors, including:

- **Financial Incentives:** While there are currently no federal incentives for the installation of SWT, many states offer some combination of rebates (i.e., buy-down programs), grants, tax credits (production, sales, or property), loan funds, and net metering (see next bullet). In particular, AWEA (2002b) notes that 10 states offer rebates or grants, 14 states offer personal or corporate income tax incentives, 10 states offer sales tax exemptions, 18 states offer property tax exemptions or abatements, 15 states offer loan funds, and 33 states allow net metering. Forsyth (2000) examined the impact of various incentives on payback periods, and concluded that buy-down programs (i.e., rebates or grants) offer the strongest financial incentive, followed by net metering and then tax incentives.

- **Favorable Policy:** Net metering policies allow a self-generator to "bank" excess generation on the grid (and at the more valuable retail rate) by spinning the meter backwards. To take advantage of net metering, however, a customer must first be able to interconnect to the grid. Depending on the utility involved, the interconnection process can be onerous and expensive for the customer – often enough so to discourage the customer from proceeding with the project (Alderfer et al. 2000). The renewable energy industry (and particular the PV industry) has for years called for a simplified and standardized model interconnection agreement, and FERC recently released a draft *national* interconnection standard for public comment.
- **High Retail Electricity Prices:** The higher the price of power that on-site wind generation offsets, the more favorable on-site generation looks. This is particularly true with net metering.

4.3 Barriers to Market Growth

EPRI (2001b) cites the most important research needs to overcome barriers to SWT development in the U.S. as:

- **Raising consumer awareness:** Most consumers do not know that SWT are a viable option for the home.
- **Implement accommodative zoning regulations:** Current height restrictions in many residential areas prohibit the use of recommended-height towers, thereby greatly eroding the performance and economics of SWT.
- **Resource assessment:** The SWT industry complains that the DOE's wind power maps are not of high enough resolution to be useful for those interested in SWT. Furthermore, industry charges that the DOE has confused many potential SWT customers by generally failing to distinguish between the resource needs of large and small wind turbines. For example, the DOE's focus on Class IV or better wind sites applies only to the utility-scale market – most SWT will work in Class II or better – yet this is seldom stated in a clear manner.
- **Better inverters:** Develop better inverters that can handle variable voltage output (most are built to handle constant voltage); i.e., make inverters specific to small wind turbines, as Bergey has done with the GridTek 10 (manufactured for Bergey by Trace).
- **Move towards mass production:** The SWT industry is poorly tooled for mass production, yet the small size of the current market makes acquiring the necessary tools difficult to justify.

To this list of barriers, Bergey (2001a) adds:

- **A lack of federal tax incentives for SWT:** Whereas PV, geothermal, and large wind installations are all currently eligible for federal tax incentives, small wind is not.
- **Onerous interconnection standards**, which can double the cost of a grid-connected system and stifle market growth. In an effort to facilitate interconnection of distributed generation and curb any discrimination by utilities, FERC has recently released a draft national interconnection standard for public comment.

Finally, concerning village power applications, unsubsidized electricity prices in Alaskan villages are $0.42/kWh on average, but the Alaskan state government subsidizes electricity prices down to \$0.20/kWh using state oil revenue. This "hidden cost" of using diesel reduces the economic incentive to install wind power.

4.4 SWT Costs

As with utility-scale wind turbines, cost information for small wind turbines is hard to come by. On the one hand, turbine equipment costs are somewhat transparent, given the retail nature and residential focus of the market. On the other hand, installation costs seem to vary widely, making total installed costs difficult to peg, particularly since turbine equipment costs typically represent only 12%-48% of the total installed cost of a small wind-electric system (Sagrillo 2002). Below we present what information we have been able to find on installed capital costs, as well as operating and maintenance costs.

4.4.1 Capital Costs

EPRI (2001b) cites the installed cost of SWT as ranging from \$1.5/W to \$4/W, and also provides a breakdown by turbine size, as depicted in Table 21. The cost of power (\$/kWh) shown in the final column of Table 21 varies widely based on different assumptions for both the quality of the wind resource as well as financing structure.

Table 21: Installed Capital and Energy Costs of SWT

Turbine Size	Application	Installed Costs	\$/kW	\$/kWh
1-2 kW	On-grid	\$3,000-\$12,500	\$3,000-\$12,500	0.25-1.25
10 kW	On-grid	\$24,500-\$35,000	\$2,450-\$3,500	0.13-0.76
	Off-grid	\$61,500-\$87,000	\$6,150-\$8,700	0.30-2.00
50 kW	On-grid	\$85,000-\$100,000	\$1,700-\$2,000	0.05-0.28

Source: EPRI 2001b

Data from two Atlantic Orient AOC 15/50 projects imply that EPRI's cost estimates for 50 kW turbines in Table 21 are optimistic. Reports from the Turbine Verification Program indicate that the installed cost of the first three AOC 15/50 turbines in Kotzebue, Alaska came to approximately \$3/W (EPRI 1999). More recently, the Long Island Power Authority (LIPA) has installed the first of five AOC 15/50's on farm sites in Suffolk County, reportedly at a cost of \$4.50/W (AWEA 2002c). Reasons for this disparity in installed costs are not clear, and AOC was not reachable for comment. One possibility, however, is that the Kotzebue costs covered three turbines, potentially resulting in economies of scale not available to the single LIPA turbine.[16] Another potential factor is that the AOC 15/50's in Kotzebue are actually rated at 66 kW (through the use of larger blades) rather than 50 kW, perhaps making them more cost-effective on a \$/W basis (depending on the relative cost of the larger blades).

Moving down the size scale, AWEA (2002a) contends that in 2002, the installed cost of a typical 5-15 kW residential wind turbine is about \$3,500/kW. By 2020, the industry hopes to reduce installed costs to between \$1,200/kW and \$1,800/kW (a >50% reduction), which would bring the 30-year life cycle cost of energy to \$0.04-\$0.05/kWh (AWEA 2002a). The SWT industry

[16] Though any economies of scale would presumably be offset by exorbitant shipping charges to Alaska (north of the Arctic Circle), as well as any additional cold weather features necessitated by the harsh environment.

estimates that high-volume manufacturing could contribute 15%-30% to this cost reduction (AWEA 2002a).

Information provided by SWT manufacturers largely supports this data (which should not be surprising, since all major domestic SWT manufacturers were instrumental in developing the AWEA roadmap). Bergey's website lists prices for a number of "value packages" (including two wind/solar hybrid packages) that include all the hardware necessary for a complete system, targeted to different applications. For complete installed costs, one would have to add the cost of shipping, sales tax, permit costs, foundation and anchoring, wire run, turbine and tower erection, electrical hook-up, battery racks or vaults (depending on package), and inspection fees. Bergey suggests both a low and high estimate of these installation-related costs, depending on whether the package is installed by the customer or a certified dealer.

Table 22 lists the five wind-only (i.e., non-hybrid) packages offered by Bergey, along with equipment costs and low and high estimates of total installed costs (all in \$/kW). Note that equipment prices for some of the packages are suggested retail prices, which are the prices that Bergey dealers typically charge. Bergey also provides factory-direct prices (Bergey.Direct), which could be up to 5% lower than the equipment prices shown for some of the packages (particularly the smaller sized packages) in Table 22.

Table 22: Cost Data for Bergey's Value Packages

Bergey Value Package	Application	Equipment Cost (\$/kW)	Estimated Installed Cost Low (\$/kW)	Estimated Installed Cost High (\$/kW)
1 kW Remote	Remote Home	\$3,275	\$3,775	\$4,775
2 kW Home.Sure	Bill Reduction & Backup Power	\$4,745	\$5,245	\$6,745
7.5 kW Home.Sure		\$5,988	\$6,655	\$8,655
7.5 kW Remote	Remote Home	\$4,757	\$5,290	\$7,423
10 kW GridTek	Bill Reduction	\$3,073	\$3,323	\$3,873

Source: www.bergey.com

Bergey's on-line cash flow calculator calculates that a cash purchase of Bergey's 10kW GridTek system for \$35,000 (installed) will have a simple payback period of 20 years. This assumes a capacity factor of 14%, a retail electricity rate of \$0.12/kWh (escalating at 2%/year), O&M costs of \$0.005/kWh (escalating at 3%/year), and no state or federal incentives. This same system in California – now mysteriously costing \$45,000,[17] offsetting a retail electricity price of \$0.22/kWh, and taking advantage of the CEC's 50% rebate and the state's 15% income tax credit – pays for itself in only 7 years, thereby demonstrating the power of both incentives and high retail rates.

Table 23 shows a breakdown of installed costs for a Bergey 10 kW system. Equipment costs (turbine and tower) make up 78% of the total, while delivery and installation account for 15% and permits and taxes the remaining 7%.

[17] This \$10,000 California price premium is perhaps a subconscious acknowledgement of the price gouging that has occurred in California following the surge in demand during the state's electricity crisis (more on this below).

Table 23: Installed Cost Breakdown for Bergey 10 kW System

Item	Description	Price	% of Total Installed Costs
1	10 kW Excel-S Turbine & Inverter	$20,900	58%
2	100 ft GL Tower Kit	$6,900	19%
3	Tower Wiring Kit	$930	3%
4	Shipping & Delivery	$1,000	3%
5	Foundations	$1,000	3%
6	Wire Run (300 ft)	$900	2%
7	Electrical Contractor	$650	2%
8	Turbine Set-Up (including crane)	$950	3%
9	Misc. Costs	$500	1%
10	Building Permit	$400	1%
11	Sales Tax (7.25%)	$2,033	6%
	Total:	**$36,133**	**100%**

Source: Bergey 2001a

Most of the data presented so far in this section is sourced from Bergey and the SWT industry. While it is useful to know what the industry thinks about the installed cost of SWT, for data on *actual* installed costs of *real* projects, we now look to data provided by the CEC in conjunction with its buy-down program. Figure 11 breaks out the average cost of all completed SWT installations (blue bars, primary y-axis) through March 2002 by turbine size category (x-axis). The number of turbines in each size category is also shown (red dots, secondary y-axis). In total, the data represents 119 turbines with an average cost of $6/W. Most of the installations (88 of the 119 total) are concentrated in either the smallest (0-1 kW) or largest (8-10 kW) size category. This is perhaps not surprising, given the limited number of turbines that qualify for the CEC's program, and the bi-modal size distribution exhibited by those turbines (see Table 18).[18] Also note that, as one would expect, the average installed cost declines as turbine size increases, with the 0-1 kW category averaging $7.50/W and the 8-10 kW category averaging just over $4/W (i.e., higher than Bergey's "high" estimate for the 10 kW GridTek value package).

[18] In fact, given the list of eligible turbines presented in Table 18, one might wonder how there could be any installations of between 3 and 8 kW. Though not entirely clear, we believe that these six installations must represent combinations of multiple smaller turbines.

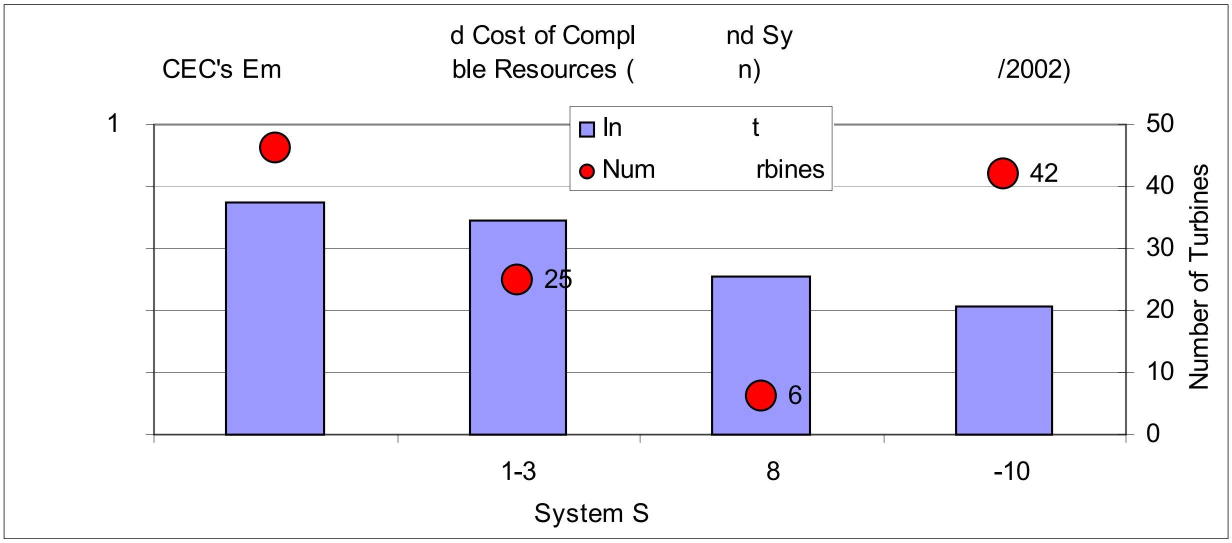


Figure 11: Average Installed Cost of Completed SWT Systems, January 1998-March 2002

While the CEC buy-down program represents perhaps the best source of actual installed SWT costs in the U.S., one must keep in mind several factors that potentially influence the data. One problematic feature of the CEC program (over the period featured in the chart) is that it set a single incentive level ($4.50/W up to 50% of installed costs) for all systems regardless of technology, be it PV, small wind, or renewable fuel cells. In effect, this meant that for small wind, the 50% cap would virtually always be binding, which lead to gaming of the system in several ways. For example, if an installer knows that the CEC will pay for half of whatever he can talk the customer into buying, he is much more likely to attempt to "gold-plate" the system and sell the customer unnecessary bells and whistles. Furthermore, prior to 2003, the CEC had not set any strict requirements on the specific items it would pay for, which led to instances of blatant abuse whereby PV installers (for example) attempted to have the CEC pay half the cost of a new roof for a customer that also installs a PV system (i.e., claiming that the new roof was a necessary upgrade to enable the installation of the PV system). There have also reportedly been a few suspicious reservation requests for wind projects totaling $9/W installed – the exact amount that maximizes the dollar incentive. In other words, the design of the buy-down incentive has affected the way that dealers and installers are pricing their systems, and anecdotal evidence suggests that installers are padding their costs to maximize the incentive. If anything, this context implies that the prices exhibited above are conservative, and that small wind could be profitably installed for less, though how much so is not clear.

4.4.2 <u>O&M Costs</u>

We were unable to find any reliable estimates of operations and maintenance (O&M) costs for small wind turbines. As noted above, Bergey includes $0.005/kWh O&M costs (escalating at 3%/year) in his on-line cash flow calculator. We view this as a low estimate, however, since experience with grid-tied PV installations suggests that inverters seldom last longer than 7-10 years, implying that over its 30-year design life a SWT will burn through at least two inverters (assuming similar lifespan of SWT inverters). The costs of inverter replacement alone could easily exceed $0.005/kWh.

At the other end of the spectrum, Forsyth (2000) assumes that annual O&M costs are 1% of the installed turbine costs. Taking 1% of the $36,133 installed cost of the Bergey 10 kW system shown in Table 23 yields annual O&M costs of $361. Spreading $361 over 12,000 kWh/year (i.e., the same 14% capacity factor that Bergey's payback analysis uses) yields variable O&M costs of $0.03/kWh – substantially higher than Bergey's assumption of $0.005/kWh.

Blanko et al (2002), meanwhile, estimate annual O&M costs for a 50 kW AOC turbine to equal $2000, while a Northern Power 100 kW turbine is estimated to have annual O&M costs of $3500. At the same 14% capacity factor as above, this equates to O&M costs of 2.8-3.4¢/kWh.

Though they vary considerably, the Bergey, Forsyth, and Blanko estimates are merely modeling assumptions; obtaining actual field data (or even marketing claims) on O&M costs is a challenge to say the least. This is perhaps not surprising, given the small and decentralized nature of the market, as well as the variety of applications for which SWT can be utilized. Furthermore, today's SWTs are designed for reliability with only 2 or 3 moving parts, and many SWT manufacturers therefore like to claim that their turbines are "maintenance-free." In other words, highlighting no (rather than low) O&M costs seems to be the preferred marketing strategy.[19]

O&M cost data is lacking for even the most highly documented SWT project we encountered. The development and operation of the Kotzebue Electric Association's wind/diesel hybrid system utilizing Atlantic Orient's AOC 15/50 turbines (66 kW each) has been painstakingly documented through the DOE's Wind Turbine Verification Program (TVP). While the TVP reports for the first and second year of operating experience provide detailed information on turbine availability and outages, they are unable to provide an estimate of O&M costs because most of the O&M occurred under warranty with AOC (the project is only a few years old). That said, if Wind Sail is interested in detailed technical information on the development and operating experience of large (66 kW) SWTs sited in a harsh climate (north of the Arctic circle) and operating in conjunction with diesel generation, the three TVP reports on the Kotzebue project are worth reading (EPRI 1999, 2000, 2001a).

Unfortunately, perhaps more often than not, SWTs that have ceased to function properly after the warranty period may simply be shut down, rendering O&M costs somewhat meaningless and elevating the importance of "time in service" as an indicator of turbine quality. Along these lines, Sagrillo (2002) states that experience from the field indicates that the "heavyweights" – heavy duty, metal, slow-speed turbines – will last their 20-year design life and even longer (and then can be completely overhauled and placed back in service), while the light-weight, high-speed turbines may last only half (10 years) or a quarter (5 years) as long, assuming diligent maintenance. For this reason, Sagrillo (2002) favors the "beasties," and considers $/pound and weight/tip-speed-ratio to be the two most important indicators when comparing turbines. Heavyweight turbines (e.g., Bergey, Jacobs, Proven) cost more up-front, but are more

[19] Sagrillo (2002) points out that despite the manufacturers' claims, it is unrealistic to expect something as complex as a wind turbine, operating continuously in a harsh environment, to work flawlessly with no maintenance. Most of the catastrophic failures he has seen over the years were attributable to something as minor as a bolt coming loose and not being attended to. He therefore advocates a thorough inspection of the entire system once a year, at a minimum.

economical over the long term. In this sense, being "built like a Russian tank" may prove to be an asset to Wind Sail.

4.5 The Competition: Other Technologies, Other Small Wind Turbines

4.5.1 Other Technologies

The two main competitors facing SWTs are diesel generators and PV systems. Fortunately, SWT can and have worked well in harmony, rather than competition, with both. Below we provide some estimates of the installed capacity of PV and diesel installations in the US and globally, as well as cost estimates for both technologies. Note that the availability of data – particularly for diesel generators – is limited (or at least we were not able to find much), making it difficult to assess the quality of the data presented.

Diesel Generators
Data on the installed capacity of diesel generators in the US and abroad has been difficult to come by. Further exacerbating data collection efforts is the fact that only certain diesel applications (e.g., baseload power) using certain size generators (e.g. <100 kW) are likely to be relevant competitors to Wind Sail. Data on generators used for backup, standby, or emergency power, as well as data that includes large generators, is likely to not be very useful. With these caveats in mind, what follows is the best information we could find (without spending an inordinate amount of time searching).

A database of *backup* generators in California compiled by Arthur D Little (ADL) in 2001 from interviews with Air Quality Management Districts estimates that there are over 4,000 diesel generators in the state with a total installed capacity in excess of 3,200 MW. Data quality issues (e.g., only generators in excess of 300 kW are included) lead ADL to think that these numbers are conservative. Furthermore, much of this data was collected in early 2001; expectations of frequent rolling blackouts during the summer of 2001 may have substantially boosted backup diesel generator installations in California since then.

A different industry survey implies a far higher number of generators in California: >24,000 units in excess of 300 kW. These higher numbers may in fact be closer to reality, as many units may have been installed without notifying the local air permitting authority. In addition, Table 24 (taken from this survey) shows a far greater number of smaller diesel generators (i.e., <300 kW).

Table 24: California Engine Generator Sets

Nameplate kW	Units Installed as of January 1997	Units Installed as of April 2001
50-75	22,405	27,233
71-150	23,558	28,635
151-300	14,373	17,470
301-700	7,062	8,584
701-1200	5,259	6,392
1201-2000	5,257	6,390
2001-	1,968	2,392
Total Installed	**79,882**	**97,097**

Source: Celerity Energy, LLC

On a national level, using 1996 data obtained from the EPA, Table 25 breaks out total installed diesel generator capacity in the US by size. 51% of the generators represented by this data are believed to be stationary, rather than mobile. Note that this data is relatively old, and more recent nationwide estimates could not be found.

Table 25: Total Installed Diesel Generator Capacity in the United States, 1996

Size	Installed Units	Average Kilowatts	Installed Capacity
2.2 – 4.5 kW	6,235	4.2	26.4
4.5 kW – 8.2 kW	34,543	6.2	212.9
8.2 kW – 11.9 kW	40,262	10.4	417.5
11.9 – 29.8 kW	104,448	19.3	1,898.2
29.8 – 74.6 kW	153,705	53.6	8,104.9
74.6 – 130.6 kW	108,415	100.7	10,918.5
130.6 – 223.8 kW	72,434	183.5	13,292.8
223.8 – 447.6 kW	49,690	320	15,902.5
447.6 – 746 kW	38,318	560.2	21,467.4
Over 746 kW	24,674	1,208.5	29,819.5
Total	**626,489**	**166 kW**	**102,061 MW**

Note: Totals do not match due to rounding.

Source: Virinder Singh, "Blending Wind and Solar into the Diesel Generator Market", Renewable Energy Policy Project, Winter 2001

A 1994 business plan for a new (then) joint venture between Bechtel and Pacificorp contains some indication of worldwide shipments of *baseload* diesel generators, broken out by size. Table 26 is compiled from this data. Note that this data is old, and that the projections to 2005 were made back in 1994 (not in 2002). Also note that projected growth rates are low, indicative of the mature nature of diesel gen-set technology. Data on larger generators is available, but is excluded from this table. Country-specific data is also available by sector, though not by generator size.

Table 26: Worldwide Baseload Gen-Set Shipments and Average Growth Rates

Sector	Size Range	1990	1995	2000	2005	Avg. Growth (%)
Consumer	<50 kW	75	100	123	150	4.7
	51-300 kW	153	208	257	315	4.9
Commercial	<50 kW	70	82	86	88	1.5
	51-300 kW	344	441	514	584	3.6
Agricultural	<50 kW	18	23	27	30	3.5
	51-300 kW	81	107	128	149	4.2
Industrial	<50 kW	59	75	86	98	3.4
	51-300 kW	583	704	769	833	2.4
Institutional and Utility	<50 kW	15	15	14	13	-0.7
	51-300 kW	189	199	187	176	-0.5

Source: EnergyWorks business plan, October 17, 1994

Diesel generators have historically been the default technology for powering remote, off-grid villages. However, wind/diesel or wind/diesel/solar hybrid systems are gaining favor because the combination of technologies provides a more cost-effective and reliable power system than is possible using any of the technologies on their own. Table 27 depicts the complementary nature of wind and diesel generation.

Table 27: Complementary Nature of Wind and Diesel

Characteristic	Wind	Diesel
Capital Cost	High	Low
Operating Cost	Low	High
Logistics Burden	Low	High
Maintenance Requirements	Low	High
Available On-Demand	No	Yes

Source: Bergey 2000

At least two wind/diesel hybrid power systems in the U.S. have been well-documented: the Kotzebue Electric Association's project in Alaska (involving wind turbines from both Atlantic Orient and Northern Power Systems) and the U.S. Navy's installation on San Clemente Island off the coast of southern California (involving four 225 kW NEG Micon turbines).

The following paragraph, taken directly from McKenna and Olsen (1999), estimates the operating cost of the Navy's diesel generating system on San Clemente Island:

> "The diesel system operating costs are derived partly from San Nicolas Island cost data because the San Clemente Island (SCI) information is incomplete. Fuel costs are based on various memos, email and verbal conversations with the PWC. Since a full breakdown of SCI power system costs was not available, we resorted to the rate SCI charges its customers: $0.390/kWh, which gives $2,971,205 for 7,618,475 kWh. The inherent assumption is that this rate reflects true and total life-cycle costs for the SCI power system without profit, since its customers are other Navy entities and their subcontractors. We suspect the true diesel system costs are lower, but don't have any other basis to work with at this time. The fuel price also is known, at $0.206/liter ($0.78/gal), and adding transportation and other hidden costs bring the total fuel cost up to $0.264/liter ($1.00/gal). That translates into $0.082/kWh for fuel using the baseline fuel and energy totals for 1998. The remaining amount of $0.308/kWh is included in the O&M item in the economic analysis spreadsheet, but it must cover O&M, diesel overhauls, and eventual replacement. However, some of these costs are fixed and part variable. We will assume they split half-and-half, based on experience with similar facilities. Therefore the variable part is $0.154/kWh, and the fixed part is 0.5*(0.308*7,618,475) = $1,173,245."

McKenna and Olsen (1999) also report the results of some modeling they did, which shows that the four 225 kW NEG Micon turbines reduce the cost of energy from the diesel system from \$0.476/kWh to \$0.447/kWh (a 6.1% reduction), giving an IRR of 14.8% and a 6.3 year payback period on the wind turbines.[20]

Similar data is not available for the Kotzebue Electric Association (KEA), which runs six diesel generators totaling 11.2 MW, though data from the last five years (prior to the addition of the wind turbines) indicate that KEA used 1.4 million gallons of diesel fuel per year with an average efficiency of 14-15 kWh/gallon of fuel (EPRI 2001a). The efficiency of the diesel generators on San Clemente Island is similar, at around 13 kWh/gallon (McKenna and Olsen 1999).

Using wind to supplement diesel in wind-diesel hybrids has also been found to be potentially economic in some of the islands off of the New England coastline (Blanko et al. 2002). In that study, a diesel only system is estimated to cost 31¢/kWh. Supplementing the diesel gen-sets with six 250 kW wind turbines was estimated to reduce the cost of delivered electricity to 26¢/kWh. Another New England island that relies entirely on diesel has an estimated cost of 39¢/kWh. Finally, Chinese documents indicate that rural electrification with diesel gen-sets alone can cost as much or more than 36¢/kWh.

LBNL data on 67 different diesel generators from 3 different manufacturers suggests that equipment costs can range from \$127-\$878/kW, while installation costs (for a subset of the generators) range from \$39-\$433/kW, bringing turnkey costs to between \$175-\$1,311/kW (http://der.lbl.gov/). Fixed O&M costs of \$26.5/kw-yr are assumed. These data are now at least 2-years old.

Photovoltaics (PV)

A May 2002 NREL report estimates total installed PV capacity in the US. NREL pegs on-grid capacity at 26.6 MW, and cites other studies that have estimated off-grid capacity to be anywhere in the range from 100-150 MW (see Table 28). (Note: For comparison purposes, around 15 MW of small wind capacity is reportedly installed in the US).

Table 28: Cumulative PV Capacity in the US through 2000 (MW)

Source	On-Grid (MW)	Off-Grid (MW)	Years Included
Paul Maycock	40.1	98.7	1992-2000
EIA	30.6	150.4	1982-2000
NREL	26.6	#N/A	through 2000

Source: Price et al. 2002

Of the 26.6 MW of on-grid capacity, NREL estimates that 55% is serving the commercial sector, 28% is central station, while 17% serves the residential market (see Table 29).

[20] The reason for the discrepancy in diesel costs between this paragraph and the previous (i.e., \$0.476/kWh vs. \$0.39/kWh) is not entirely clear, though it may simply be that the \$0.476/kWh is the product of a modeling exercise, whereas the \$0.39/kWh is the actual rate that the Navy charges its customers on the island.

Table 29: Sector Breakdown of On-Grid PV Capacity in the US through 2000 (MW)

Residential	4.6
Commercial	14.6
Central Station	7.4
Total	26.6

Source: Price et al. 2002

Globally, roughly 300 MW of PV was installed in the year 2000 (compared to roughly 30 MW of small wind), bringing total installed capacity worldwide to more than 1,000 MW. Japan, home to the world's largest PV market, installed almost 110 MW in 2000, bringing cumulative PV capacity in that country to nearly 320 MW. Germany, on track to surpass the US as the world's second largest market, installed 45 MW in 2000, bringing total installed PV capacity to more than 110 MW.

Table 30 breaks down total U.S. PV production in 2000 by end-use application (for both domestic use and exports). Grid-tied generation leads the pack at nearly 22 MW, compared to just 469 kW in 1990, while remote generation comes in second at 15 MW, compared to just over 3 MW in 1990. This is an interesting flip-flop of the dominance of grid-connected and off-grid markets, suggesting that PV is becoming more mainstream. Whether on- and off-grid SWT have similarly crossed paths yet is unclear, though Table 19 projects that, at least in the U.S., grid-connected SWT will far outnumber off-grid SWT applications by 2020.

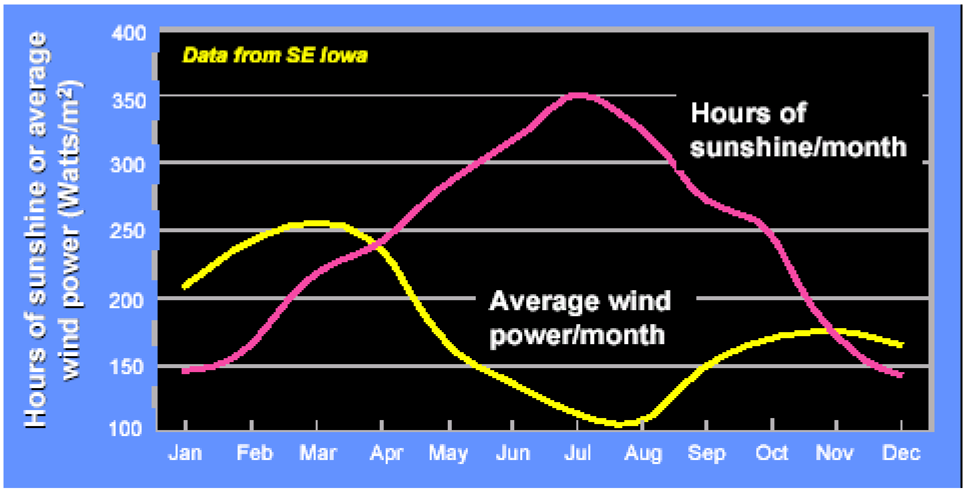
Table 30: Fate of U.S. PV Production in 2000

PV Application	kW(peak)	% of Total
Grid-Tied Generation	21,713	25%
Remote Generation	14,997	17%
Transportation	12,804	15%
Communications	12,269	14%
OEM Applications**	12,153	14%
Water Pumping	5,644	6%
Consumer Goods	2,870	3%
Health	2,742	3%
Other	3,028	3%
Total:	**88,221**	**100%**

***Original Equipment Manufacturers (OEM) fabricate products for sale to end users*
Source: EIA 2002

While the cost of energy from PV systems is typically several times more expensive than the cost of energy from a small wind turbine, PV has the advantage of being highly modular, easy to transport, easy to site, and relatively easy to maintain (with no moving parts), thereby making it a preferred renewable energy technology for remote off-grid homes, particularly in developing countries. Furthermore, at very small turbine sizes, PV may even look economical relative to small wind. In other words, the smaller the wind turbine, the more expensive it is, and therefore the more competitive PV appears to be.

As with diesel, however, wind power often complements PV production rather than directly competing with it, since the wind tends to blow more strongly when the sun is at its weakest (i.e., in winter). Figure 12 shows the complementary nature of solar and wind power in southeast Iowa.



Source: Bergey 2000

Figure 12: Complementary Nature of Wind and Solar

Compared to the U.S. SWT industry, which consists of a handful of companies, there were 21 U.S. companies involved in the production of 88,221 kWp of photovoltaics in 2000, up from 13,813 kWp a decade ago (EIA 2002). The average cost was $3.46 per peak watt for modules and $2.40 for cells, compared with $5.69 and $3.84 a decade earlier.[21] This represents a 540% capacity increase (20% annualized), and a 38% price decline (4.7% annualized).

4.5.2 Other Small Wind Turbines

As mentioned earlier, there are over fifty SWT manufacturers in the world today, offering a variety of different models. AWEA (2002a) notes, however, that while large utility-scale wind turbines are in their 7th or 8th generation of technology development, SWT are only in their 2nd or 3rd. In fact, the old Jacobs turbines, which have not been manufactured for over 50 years, are still considered by many to be top-of-the-line technology, which is why several companies are now engaged in the business of refurbishing the old Jakes (Sagrillo 2002). Given the relatively "unrefined" state of SWT technology, Wind Sail – being a new entrant to the market – may not be at as much of a disadvantage as it would otherwise be trying to break into the utility-scale market. On the other hand, Wind Sail's envisioned gearless technology may not hold as much of an advantage in the SWT market as it otherwise might in the utility-scale market: most SWTs are already direct drive, variable speed systems with permanent magnet generators. Furthermore, AWEA (2002a) notes that "Some new entrants to the industry have significantly underestimated the engineering rigor and expense required to deliver a reliable small wind

[21] Note that these costs are for PV modules and cells only, and do not include balance of system components or installation costs. Total installed costs of residential PV systems have been running between $8/W and $11/W in the U.S.

turbine product." Exaggerated claims have led to consumer confusion and mistrust, spurring AWEA to call for the creation and implementation of small wind turbine standards and certification programs – something for Wind Sail to keep an eye on as it designs its product.

Table 31 (on the next page) provides basic information on all of the SWT manufacturers we were able to find, as well as web links where Wind Sail can pursue further information on each. Immediately following Table 31, we provide more detailed information on the most prominent domestic HAWT manufacturers, as well as basic data (and pictures) for all VAWT manufacturers that we came across (prominent or not), given Wind Sail's interest in VAWT technology. While looking through this information and considering the merits of each company's product (and Wind Sail's), keep in mind the SWT industry's vision of the "turbine of the future" (AWEA 2002a):

- Will have to be specially designed to work in low wind resource areas, having larger rotors to capture more energy
- Will still need to be robust, because even low wind speed areas experience severe weather
- Must be extremely quiet
- Must be able to operate for 10-15 years between inspections and/or preventive maintenance
- Must offer a reasonable expectation of a 30- to 60-year operating life
- Must be affordable without subsidies

Table 31: SWT Manufacturers (or in some cases, distributors)

Company Name	Web Address	Country	Product Range
Horizontal Axis			
Amp Air	www.ampair.com	UK	100W
Atlantic Orient Corporation	www.aocwind.net	US	50kW
Bergey Windpower	www.bergey.com	US	1-50kW
J.Bornay Wind Turbines	www.bornay.com	Spain	250W-6kW
Gazelle	www.mkw.co.uk/renewable.htm *or* www.northenergy.co.uk/	UK	20kW
Aerogen Wind Turbines (LVM)	www.unlimited-power.co.uk/Aerogen_wind_turbines.html	UK	48-360W
Pitchwind	www.pitchwind.se/	Sweden	20-40kW
Proven	www.provenenergy.com/	UK	600W-6kW
Southwest Windpower	www.windenergy.com/	US	400W-3 kW
Synergy Power Corporation	www.synergypowercorp.com/	Hong Kong	125W-30kW
Vergnet	www.vergnet.fr/index3.html	France	1-225kW
WindStream Power Systems	www.windstreampower.com/	US	120W
Wind Turbine Industries Corporation	www.windturbine.net/	US	20kW
MGx LLC	www.mgx.com/	US	1.5-3kW
Abundant Renewable Energy	www.ahanw.dhs.org/abundantre/ (re-manufactures Jacobs turbines and distributes African Wind Power turbines)	US	2.4-3.6kW
Northern Power Systems	www.northernpower.com/framesets/sub1_products.html	US	100kW
Mass Megawatts	www.massmegawatts.com/	US	modular
Marlec Engineering	www.marlec.co.uk/ (Rutland Windchargers)	UK	25W-??
Aerocraft	http://www.aerocraft.de/	Germany	120W-1kW
Westwind Wind Turbines	http://www.westwind.com.au/	Australia	3-20kW
Fortis Windenergy	www.fortiswindenergy.com/	Netherlands	100W-30kW
Vertical Axis			
Wind Harvest	www.windharvest.com	US	25kW
Sustainable Energy Technologies	www.sustainableenergy.com/renewable/wind.html	Canada	250kW
Shield (Jaspira)	www.shield.fi/	Finland	20W-10kW
WindSide	www.windside.com/	Finland	20W-7.5kW
Ropatec	www.ropatec.com	Italy	0.5-6kW
Ampair	www.ampair.com	UK	4W
Terra Moya Aqua (TMA)	TMA does not have a web site	US	20-750kW
The Turby	www.turby.nl	Netherlands	2 kW

Major Domestic SWT Manufacturers

Bergey Windpower *(www.bergey.com)*

Since its establishment in 1977, Bergey Windpower has completed over 2,100 turbine installations, reportedly in all 50 states and 90 countries (Bergey 2001a).[22] For example, more than 600 BWC 1000 (1 kW) turbines were sold between 1980, when the turbine was introduced, and 1990, when it was replaced by a 1.5 kW model (i.e., the BWC 1500, which itself was replaced by the Bergey XL.1 in early 2002). Originally facing 45 competitors born out of the energy crises of the 1970s, Bergey claims to have captured leading market share in 1983 with the introduction of the 10 kW Excel S, which now enjoys 80% market share in the 5-15 kW size range, with approximately 700 installations (i.e., 7 MW) to date (Bergey 2001a). Bergey's claims of market dominance are at least anecdotally supported by the SWT selected to participate in the DOE's *Field Verification Program for Small Turbines*: 13 of the 16 participating turbines were Bergey Excel C/E 10 kW, tested in various applications (DOE 2002).[23] Bergey currently offers the industry's longest warranty, at 5 years (most other manufacturers offer 2-3 years at most).

Though Bergey has traditionally produced turbines of 10 kW or less (with current models including turbines rated at 1 kW, 7.5 kW, and 10 kW), Bergey announced in June 2000 the development of a new 50 kW model under the DOE's Advanced Small Wind Turbine Program. Introduction of the 50 kW model, which is now expected to begin serving both the on- and off-grid markets in late 2003, has been delayed due to technical challenges involving the "bleeding edge" technologies used in the turbine, which sports only 3 moving parts and claims to be the simplest machine of its size ever built. Pricing for the 50 kW turbine has not been finalized, though we have noted three different installed cost estimates provided by Bergey in the past year or so, ranging from $100,000 ($2/W) to $130,000 ($2.6/W). More information on the new 50 kW turbine, as well as Bergey's other products, is available at www.bergey.com.

Southwest Windpower *(www.windenergy.com)*

Southwest appears to be the market leader in small battery-charging turbines. The company recently complemented its line of 400W "Air" turbines with the addition of the 900-3000W "Whisper" line that had previously been manufactured by World Power Technologies, which Southwest acquired in May 2000.

The following is taken directly from a press release announcing that Southwest had won the 2002 Small Business Exporter of the Year award from the Export-Import Bank of the United States (Ex-Im Bank):

[22] Note that 2,100 turbines is not a particularly large number, given the 25-year life of the company (i.e., <100 turbines/year). While this cumulative number is no doubt "back-loaded," with a greater number of installations in recent years, the fact that the "market leader" is only producing several hundred wind turbines per year should give pause to Wind Sail's hopes of achieving mass production on a grand scale in the near future. A similar example comes from the U.K., where Proven Engineering (the English equivalent of Bergey) – having sold just one turbine during its first year of production in 1990 – is currently producing only 100 turbines a year (expected to double with a new factory next year), and is struggling to break even (The Herald 2002).

[23] The remaining three turbines participating in the field verification program include one 900W Whisper H40 (then manufactured by World Power Technologies, which was bought out by Southwest Windpower in May 2000), and two 50 kW AOC 15/50 turbines.

"Since its inception in 1986, Southwest Windpower has produced more than 60,000 wind generators, of which 10,000 were produced in 2001 alone. The products are used to produce electricity on telecommunication towers, remote homes, off-shore platforms, remote monitoring sites, schools, and homes in emerging markets.

Founded by two young entrepreneurs out of a garage in rural Arizona in 1986, Southwest Windpower's vision from the start was to sell its products in the global market and to make a difference in the world through low-cost renewable energy. Since it began using Ex-Im Bank's export credit insurance program in 1996, the company has been able to offer its small foreign distributors open accounts, easing their cash flow and allowing them to place larger orders.

"The results have been tremendous," said Southwest Windpower Vice-President Andrew Kruse. "Last year more than 50 percent of our revenues came from export sales. We now have 50 employees, factories in Flagstaff and Duluth MN, and our products are sold in more than 50 countries. We're excited about looking at other Ex-Im Bank products to help us fill future orders. The Ex-Im Bank has become a strategic partner in our effort to further expand our export sales."

Atlantic Orient Corporation (AOC) *(www.aocwind.net)*
Based in Vermont, with turbines manufactured in Nova Scotia, AOC makes a 50 kW turbine suited for cold, harsh climates. The AOC 15/50 has been developed in conjunction with the DOE and NREL under the Advanced Wind Turbine program, and is based on an earlier Enertech 44 kW turbine. The AOC 15/50 has been widely deployed in harsh environments throughout the world, with installations in northern Alaska, Siberia, England, Scotland, Morocco, Greece, Canada, Vermont, Maine, Texas, and most recently, New York. The AOC 15/50's performance in a wind/diesel hybrid application in northern Alaska has been widely documented through the DOE's Turbine Verification Program (EPRI 1999, 2000, 2001a). Reports from the Turbine Verification Program indicate that the installed cost of the first three AOC 15/50 turbines in Kotzebue, Alaska came to approximately $3/W (EPRI 1999). More recently, the Long Island Power Authority (LIPA) has installed the first of five AOC 15/50's on farm sites in Suffolk County, reportedly at a cost of $4.50/W (AWEA 2002c). Reasons for this disparity in installed costs are not clear, and AOC was not reachable for comment. One possibility, however, is that the Kotzebue costs covered 3 turbines, potentially resulting in economies of scale not available to the single LIPA turbine. Another potential factor is that the AOC 15/50's in Kotzebue are actually rated at 66 kW (through the use of larger blades) rather than 50 kW, perhaps making them more cost-effective on a $/W basis (depending on the relative cost of the larger blades).

Despite what has seemed to be a steady (though slow) string of new orders (e.g., the 5 turbines currently being installed on Long Island), it is rumored that AOC has recently been liquidated as a result of financial problems. AOC's Canadian partner that manufactures the turbines has reportedly purchased a controlling stake in the company.

Northern Power Systems *(http://www.northernpower.com/framesets/sub1_products.html)*
Since 1979, hundreds of NPS' HR3 turbines have served remote telecommunications applications in harsh environments. NPS' newest turbine – the 100 kW Northwind 100/19 – is a direct drive turbine designed for extreme cold weather applications. The NW100/19 was

awarded R&D Magazine's prestigious "R&D 100 Award" for the most innovative technology in the year 2000. The turbine features a tubular tilt-up tower for easy maintenance.

From the NPS web site: "The NW100/19 turbine was developed by NPS with support from cooperating agencies within the U.S. government, including the National Aeronautics and Space Administration (NASA); the National Science Foundation (NSF); the Department of Energy (DOE); and the DOE-funded National Renewable Energy Laboratory (NREL). Siemens-Westinghouse acted as a subcontractor to NPS in developing the innovative direct drive generator subsystem.

Extensive field-testing has been carried out on the first turbine since its installation in Graniteville, VT in late 1998. The NW100/19 design was finalized based on these tests and performance verification. In the fall of 2000, several test sites will be solicited throughout the New England area for grid-connected applications through a DOE sponsored testing program. These projects are being implemented specifically to monitor the turbine in cold weather and distributed generation applications in order to gain operational experience. A fully tested and certified design is scheduled for 2001."

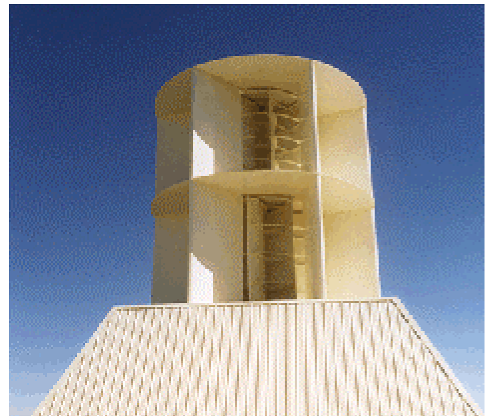
Since May 2002, a Northwind 100 has been operating alongside Atlantic Orient's AOC 15/50 turbines (and several diesel generators) in Kotzebue, Alaska. An article on the Kotzebue Electric Association's web page (http://www.kotzelectric.com/wind/wind_northwind100.html) indicates that only two other NW 100/19's exist – one in Vermont at the manufacturing facility, and the other at NREL in Colorado. This article also raises the prospect of a future market for wind turbines on the planet *Mars*, where global dust storms can often cloud the sun for weeks at a time, rendering solar power ineffective (hence NASA's sponsorship of the development of this turbine).

For technical specifications of the NW 100/19, see Northern Power Systems' web page.

Wind Turbine Industries *(http://www.windturbine.net/)*
Purchased the rights to the *Jacobs* name in 1986. Currently has only one active model listed on its web site (20 kW), although the CEC had approved a 10 kW WTI turbine for its buy-down program (production of this turbine has since been discontinued).

Global VAWT Manufacturers
Terra Moya Aqua, Inc. (TMA) *(no web site)*
TMA is a Wyoming-based VAWT manufacturer that has reportedly built turbines of various sizes (up to 1 MW). TMA has built four 250 kW units to sell power under a 20-year PPA to Tri-State G&T cooperative, and in June 2001, installed a 20 kW VAWT in Curt Gowdy State Park in Wyoming, which reportedly cost $84,000 to install ($4.20/W) (Girt 2001). TMA has also been talking to the City of Vallejo (CA) for a year or more about building 1,000 MW of VAWTs (750 kW units) as part of that city's well-publicized efforts to become energy independent through the use of renewable energy. Vallejo's Director of Community Development reports that the city is still in discussions with TMA, but is waiting for TMA to find appropriate sites and obtain the necessary permits before formalizing any type of agreement (da Silva 2002). Press reports indicate, however, that TMA has proposed to sell power to Vallejo for 20 years at 7.5 ¢/kWh,

which, though high, beats the rates that the city is currently paying PG&E (Doyle 2002). The Vallejo project stalled in January 2002 when TMA could not find financial backing, but in April 2002 TMA announced that it had partnered with Siemens AG, who will reportedly provide capital and engineering services to develop up to 1,000 MW of wind power on 3,000 leased acres outside Fairfield near Travis Air Force Base.



In addition, the U.S. Air Force is also in discussions with TMA over the installation of a single VAWT at the F.E. Warren Air Force Base outside of Cheyenne, Wyoming. The Air Force is reportedly interested in testing the turbine because it is less likely to interfere with radar than a HAWT on a tall tower.[24] If the turbine works as promised, and if radar and security impacts are minimal, the Air Force could be interested in pursuing more installations at various bases.

TMA's "stacked" and "ducted" VAWT technology relies on an external shell of "ducts" or "air intakes" used to direct the wind into the blades at the optimum angle (see Figure 13). Because the blades are protected inside the ducted shell (which resembles a small building), they can be screened with netting to prevent avian impacts.

Ropatec *(http://www.ropatec.com/)*
Italian manufacturer of VAWTs ranging from 500W to 6 kW. According to the company's web site, these turbines have been tested under extreme conditions in remote "refuges" in the Alps (see Figure 14).

Figure 14: Ropatec VAWT

WindHarvest *(http://www.windharvest.com/)*
Makers of the 25 kW WindStar VAWT (see Figures 15 and 16), Wind Harvest is based in Point Reyes Station, California, with offices in Palm Springs. Steel for the turbines comes from Stockton, while the aluminum blades are made in the Netherlands. All other components are reportedly off the shelf. Their web site claims that 20 WindStar VAWTs have been tested in real-world conditions. Personal communication with company co-founder George Wagner reveals that this testing has occurred mainly at two sites: in Wales (the U.K.) and San Gorgonio pass (near Palm Springs). In Wales, Wind Harvest – in a joint venture with Enron – reportedly had secured a lucrative long-term contract of $0.17/kWh through the Non-Fossil Fuel Obligation (NFFO) tendering process. Enron apparently walked away from the deal, which involved 5 WindStar turbines, following the energy giant's recent bankruptcy. Wind Harvest has also installed a dozen or so VAWTs in San Gorgonio over the past 10 years (to see

[24] Several planned wind farms throughout the world, including a recent project in Nevada, have been scrapped over objections from the military concerning radar interference. Because they sit lower to the ground, VAWTs may not pose such problems.

one in operation, view the video on their web site), though they currently only have 4 new turbines there (having had to move the others).

Wind Harvest's strategy is to look for high wind regime areas where they can infill WindStar VAWTs among the larger HAWTs. Wagner indicates that they can place 3-4 WindStars around the base of an existing HAWT, thereby boosting the existing wind farm's output by 20%-25%. WindStar turbines are placed only 18 inches apart – a design feature that they have recently patented – to create a "vortex" effect that boosts wind speeds through some combination of the Venturi or other augmentation/diffuser effects. WindStar turbines are manufactured for turbulent and high wind speeds, and have reportedly produced power in winds up to 80 mph. When asked about the limitations (in wind speed) of being sited close to the ground, Wagner responded that this is not always a disadvantage – on many ridge lines, you get an acceleration effect by being close to the ground (i.e., the impact is site-specific).

Wind Harvest's biggest problem is finding buyers for their power under long-term power purchase agreements – a prerequisite to being able to finance the construction of a project. This problem was exacerbated by California's electricity crisis. Wind Harvest was present at the first board meeting of the newly formed California Power Authority (CPA) in August 2001, back when it appeared as if the CPA would be signing long-term contracts for renewable power. While this never came to pass, Wind Harvest's testimony at that meeting reveals that a 25 kW WindStar turbine costs about $40,000 ($1.6/W), but that with production of 1000 units, the company is optimistic that costs would drop below $1/W (CPA 2001). George Wagner provided similar numbers, stating that the installed cost of a turbine manufactured "onshore" (i.e., as they are currently produced) would be $1.50/W, but with mass production "offshore" (e.g., sourcing steel from the Czech Republic instead of Stockton), costs would drop to $0.8-$0.9/W. These numbers assume the infill of WindStar turbines among existing HAWTs, thereby minimizing infrastructure costs (e.g., roads, wiring, substation, etc.).

In response to a question about the impact of the apparent stigma surrounding VAWT technology, Wagner responded that wind developers who truly know the WindStar technology "love them" and are not scared off by the VAWT stigma (at least in part because Wind Harvest pays them lease fees). Financiers they have approached, however, initially chuckle at the fact that they are a wind power company, then they laugh at the fact that they are a *small* company manufacturing *small* turbines, and then, finally, they laugh at the fact that they are manufacturing VAWTs as opposed to HAWTs. A common question they get from financiers is: if the WindStar technology and infill strategy is so promising, why hasn't Vestas or one of the other "big boys" acquired them as a second product line. Wagner acknowledges that they may have to partner with a more established player in order to secure financing,[25] though he did note that California utilities have finally begun to return their calls, looking to establish "a relationship" in response to the recent passage of the state's renewables portfolio standard (which obligates the utilities to increase their share of renewable energy generation by 1%/year until reaching 20% by 2017).

[25] As reported earlier, TMA has recently partnered with Siemens for this very reason.

Figures 15 and 16: 25 kW WindStar VAWT

Sustainable Energy Technologies *(www.sustainableenergy.com)*
Though this company was experiencing financial difficulties earlier in the year, it was able to raise additional equity through a private placement in May and continues to pursue development of a 250 kW 4-bladed full Darrieus VAWT known as the Chinook 2000 (see Figure 17). According to Director of Business Development David Carten (2002), they are reportedly looking at a number of financing options and partners for building the "qualification turbine" of the 250 kW Germanischer Lloyd-certified design, and have had several offers from groups in Alaska to erect Chinooks there. They have also recommissioned two of the earlier (150 kW) prototypes in Pincher Creek, Alberta. While Chinook turbines are larger than our 100 kW size threshold, we include them here anyway because of their VAWT design.

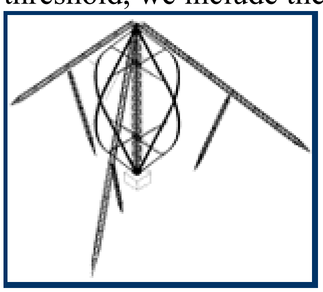


Figure 17: Rendering of Chinook 2000 Darrieus Turbine

WindSide *(http://www.windside.com/)*
WindSide is a Finnish VAWT manufacturer that supposedly has machines installed in 16 countries (and also the Antarctic). The turbines are generally small (< 1 kW), though they appear to make a 9 kW and 22.5 kW unit as well, and claim that they could conceivably scale the design to 3 MW. Because of the sculptural nature of WindSide blades, the turbines are often featured in "wind art" (see Figure 19), providing power for artistic lighting or water pumping. Like the VAWTs of another Finnish manufacturer (Shield, see below), WindSide turbines are also fairly portable, and can even be attached to a tree (see Figure 18).



Figures 18, 19, and 20: 3 Different Applications of WindSide VAWTs

Shield *(www.shield.fi)*
Shield is the Finnish VAWT manufacturer of Jaspira turbines ranging from <1kW to10kW. At the low end of this range is a hand-held, portable, lightweight, and collapsible wind turbine that can be carried by one person (see Figure 21).

Figure 21: Jaspira Turbine

Ampair *(www.ampair.com)*
Ampair – better known for its small HAWTs – has come out with a very small VAWT (4W) known as "The Dolphin" whose purpose is to top off or maintain the charge on a battery (see Figure 22).

Mass Megawatts *(www.massmegawatts.com)*
Mass Megawatts is a publicly traded company (symbol MMGW) developing a 50 kW "multi-axis" wind turbine prototype (see Figure 23) to be tested near Bakersfield, California. The

company reportedly has generated interest for several installations in Iceland, and Winrock Financial recently selected Mass Megawatts to build a 25 MW project in Colombia.

Figure 23: Mass Megawatts "Multi-Axis" Wind Turbine Prototype

The Turby *(www.turby.nl)*
This 2kW H-Darrieus from the Netherlands (designed at the Delft University of Technology) is specifically designed to be installed on rooftops, riding the European trend towards installing artistic-looking VAWTs in urban environments (see Figure 24). The Turby does not yet appear to be commercially available.

Figure 24: The Turby, with specifications

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